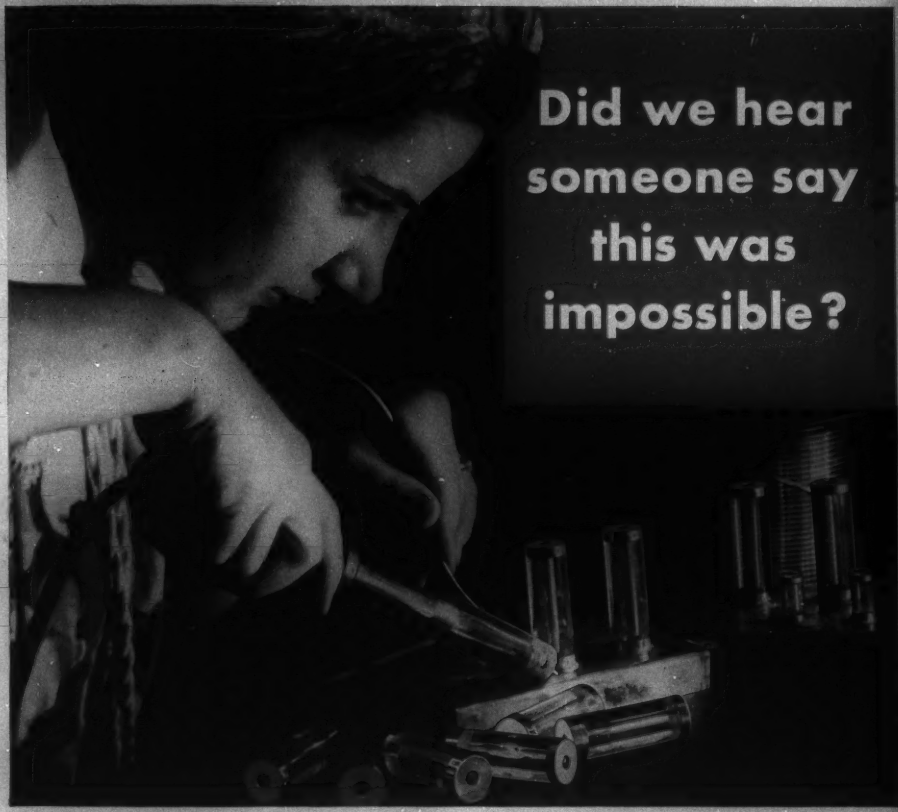
ELECTRICAL ENGINEERING

JULY 1944

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS



DOING what couldn't be done in glass has become a habit at Corning—and this is a good example. "You can't solder metal to glass"— they said. But Corning Research did it.

Now Corning has developed a metallizing method whereby the base for the solder becomes an inseparable part of the glass and so provides a permanent, air-tight seal. The metallized layer solders almost as easily as brass or copper and is not harmed by normal soldering temperatures. Parts can be soldered to it by any ordinary soldering iron, soft-air-gas flame or induction heating.

Also important—Corning type metallizing can be applied to an extremely wide range of glasses. Where extreme resistance to thermal or mechanical shock is required it can be applied to Corning's tempered glasses. Where electrical characteristics are of first importance it can be applied to Corning's special low-loss glasses.

This unique method of metallizing is just one of the ways that Corning's knowledge and experience may some day save you time and money. If you'd like to know more about us, we have a suggestion. Send for the study, "There Will Be More Glass Parts In Post-War Electrical Products." It's free. Just write to the Electronic Sales Department N-7 Bulb and Tubing Division, Corning Glass Works, Corning, N.Y.

CORNING *means* Research in Glass

Electronic Glassware

"PYREX" *and* "CORNING" *are registered trade-marks of Corning Glass Works*

Post-War Developments will create new magnet wire problems

. . . LET BELDEN WIRE ENGINEERS HELP YOU!

● When you come face-to-face with post-war production problems, you will discover many "bugs" that failed to show up in the laboratory models.

For example—coil windings. If you are building relays, motors, solenoids, or other types of electrical equipment for post-war applications, you may run into unusual coil winding specifications. Clearances may be too small, slots too tight, or corners too sharp. You may encounter unexpected insulation difficulties.

BALANCED INSULATION

Belden Magnet Wires have Balanced Insulation. Essential electrical and mechanical characteristics are combined in balanced proportions, thus reducing rejections due to poor insulation. For lowest overall winding costs, specify Belden.

Whatever your problem, call in a Belden Wire Engineer. Belden Wire Engineering Service covers all phases of magnet wire application from basic coil specifications to production.

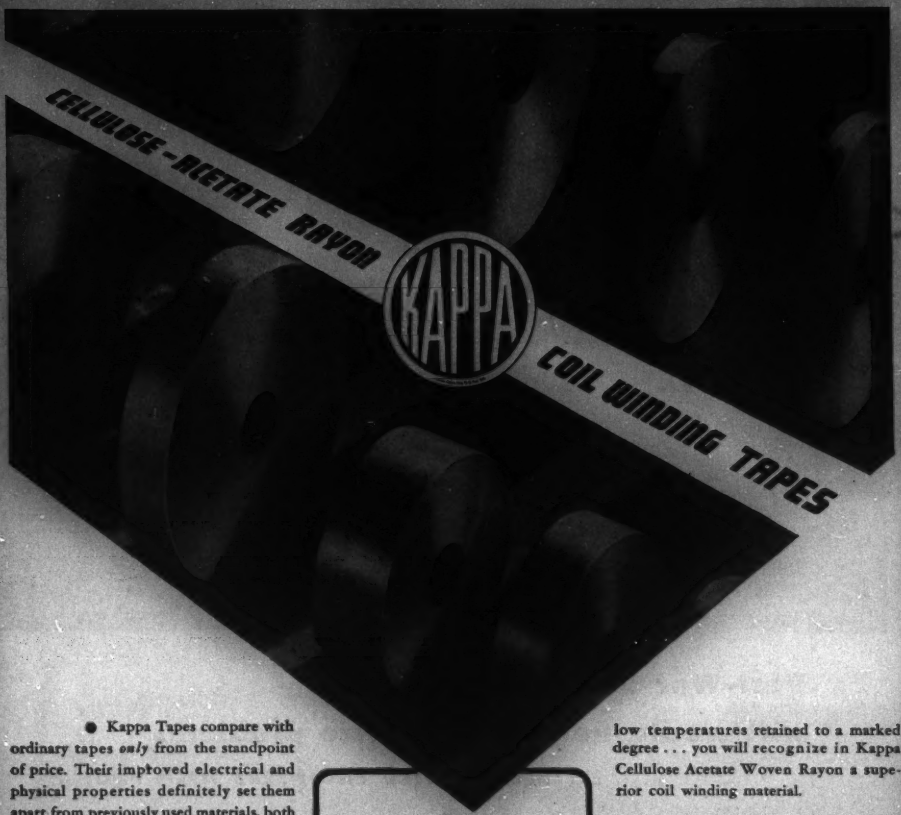
Over a third of a century of technical experience is available to you. Use it . . . save time and money . . . and cut costs.

Belden Manufacturing Company, 4635 W. Van Buren St., Chicago 44, Illinois

Belden Magnet Wires

NATURAL AND SYNTHETIC ENAMELS AND TEXTILE INSULATIONS

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York 18, N. Y. Subscription $12 per year plus extra postage charge to all countries to which the second-class postage rate does not apply; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P.L. & R. Act of February 28, 1925. July 1944, Vol. 63, No. 7. Number of copies of this issue 24,500



● Kappa Tapes compare with ordinary tapes *only* from the standpoint of price. Their improved electrical and physical properties definitely set them apart from previously used materials, both as to economy in production and superiority in performance.

This is not a fanciful claim. Laboratory and service tests of Kappa Tapes have disclosed characteristics seldom possessed by acceptable tapes with which they were compared . . . factors responsible for the ever increasing adoption of Kappa by electrical manufacturers from coast to coast.

When you consider that moisture absorption is ½ that of cotton, ⅓ of silk . . . that less varnish is required . . . that dry tensile strength is greatly increased . . . chance of deterioration considerably lessened . . . and flexibility at extremely low temperatures retained to a marked degree . . . you will recognize in Kappa Cellulose Acetate Woven Rayon a superior coil winding material.

- COMPLETE IMPREGNATION
- HIGHER DIELECTRIC
- LESS VARNISH BUILD-UP
- FEWER VARNISH DIPS
- SUPERIOR FINISH

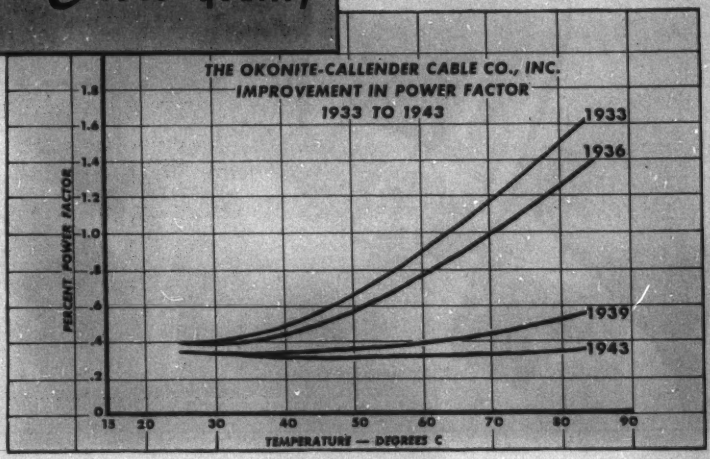
Moreover . . . breakdown voltages for varnished samples of Kappa have tested *50% higher than for ordinary tapes,* up to 10 mils (fabric plus varnish).

We believe these facts warrant your early investigation of Kappa Tapes. Write for full length testing samples to Wm. E. Wright & Sons Company, Industrial Textile Division, Box 1500, West Warren, Massachusetts

Send for this factual bulletin which presents comparative test data of Kappa and ordinary tapes.

The Wright tape for every winding.. KAPPA

the effect of ten years research on *Paper Cable* quality



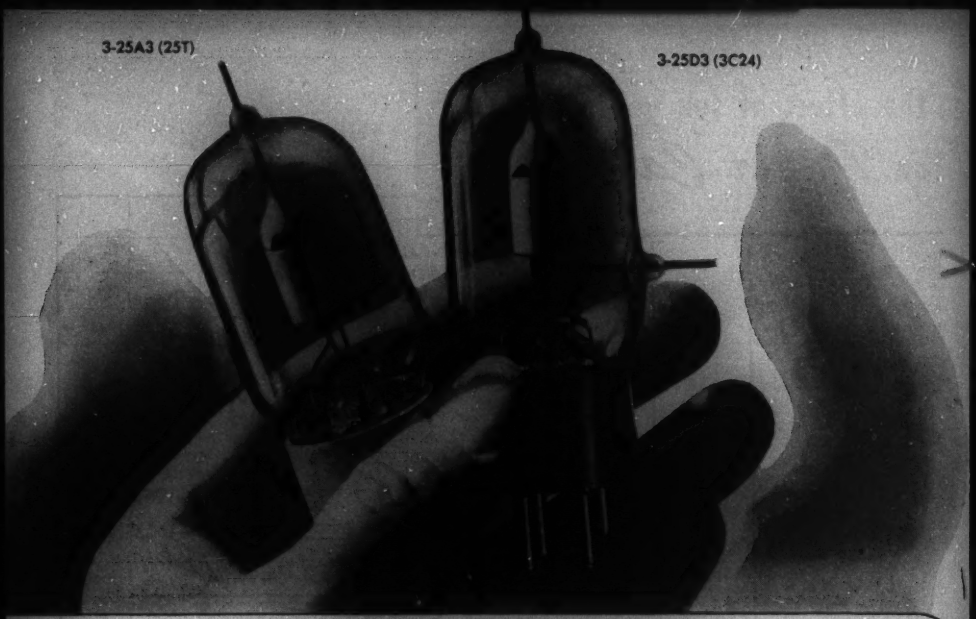
These curves show the effect of Okonite-Callender research on the quality of oil-impregnated paper-insulated cable. On the chart are plotted the averaged power factor values of samples of shielded (Type H) cable. These values have been taken from routine Test Department records of regular factory-produced cables for the years indicated.

The upper curve (for 1933) of Power Factor vs. Temperature was looked upon with pride ten years ago — as well it might have been. The lowest curve (for 1943 production) indicates the progress made in producing more uniform and more stable cable. This improvement has been brought about through continued research and is controlled through self-imposed factory specifications and skilled workmanship above and beyond any required by purchasers.

Although today's curve is approaching the ideal, our research continues in an effort to build even greater quality into future cables. Our engineers will be glad to tell you about the detailed researches that have led to these improvements and why they result in the production of cables with longer life expectancy. The Okonite-Callender Cable Co., Inc., Executive Offices, Passaic, N. J.

A newly developed and highly accurate device for determining the pH or neutralization values of insulating oil is the Fisher Electronic Titrimeter shown in use in the Research Laboratory. This together with many other Okonite-Callender testing procedures, which are regularly applied to all cables in production, provide laboratory control of all manufacturing processes essential to obtaining high-quality cable.

OKONITE-CALLENDER
PAPER INSULATED POWER CABLES



Here are TWO NEW TUBES in the Eimac line

Plate Dissipation (watts)
Amplification Factor
Filament Volts
Filament Current (amps)
Interelectrode Capacity
Grid to Plate
Grid to Filament
Plate to Filament
Maximum Ratings
(Class C amplifier)
Plate Voltage
Plate Current
Grid Current
Maximum Plate Dissipation (watts)

Follow the leaders to

Eimac TUBES

Smaller brothers of the Eimac 35T and 35TG, these two triodes are filling a need in high-frequency equipment of relatively low-powered class. They attain a high order of efficiency on frequency in the VHF range and perform equally well at lower frequencies.

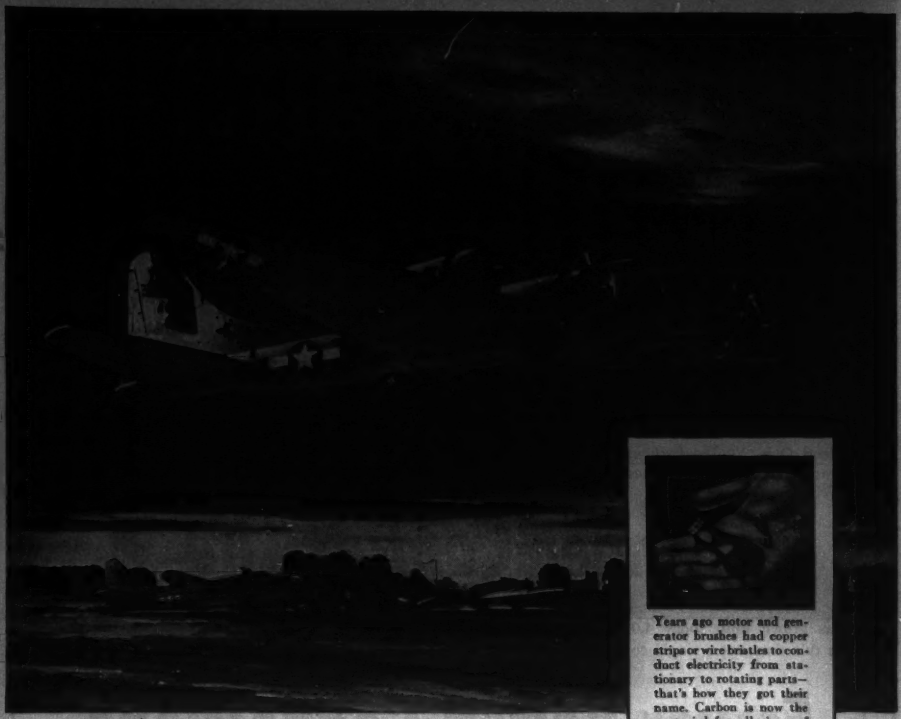
In every way these two are worthy additions to the Eimac family . . . embodying all the Eimac features including complete freedom from premature emission failures due to gas released internally.

Complete data is available without obligation. Write for it today. Also ask for your complimentary copy of *Electronic Telesis*, a sixty-four page booklet which gives the fundamentals of Electronics and many of its applications. Written in layman's language, this booklet will assist engineers in explaining the art to novices.

EITEL-McCULLOUGH, INC., 893 San Mateo Avenue, San Bruno, California

Plants located at: San Bruno, California and Salt Lake City, Utah

Export Agents: FRAZAR & HANSEN, 301 Clay Street, San Francisco 11, Calif., U.S.A.



Years ago motor and generator brushes had copper strips or wire bristles to conduct electricity from stationary to rotating parts—that's how they got their name. Carbon is now the material for all sizes of these brushes.

THEY HELP BRING THE GIANTS HOME

One of the "little things" that are contributing greatly to the safety and welfare of our fighting men, is a special kind of carbon brush used in high-altitude planes. These brushes are essential to the generators and motors that supply energy for the radios, firing apparatus, gun turrets, bomb bay doors, landing gear, and other equipment of the planes. A heavy bomber has more than 40 of these devices requiring brushes.

Ordinary brushes disintegrate in a few minutes at altitudes where the air is "thin" and dry. A brush that would be dependable from take-off to ceiling and would have a life of 100 hours or more—had to be found. It came from the laboratories of National Carbon Company, Inc., a Unit of UCC.

Carbon is useful in many other ways to Americans at war. Therapeutic lamps, which employ the carbon arc, are helping to restore health to sick and wounded men. Activated carbon in gas masks, by absorbing toxic vapors, is ready to save lives.

In the two-way radio telephone—the walkie-talkie and the handy-talkie—and in hearing aids for the deafened, carbon has another role. Carbon is essential in the small, powerful batteries that are used in these devices.

▼

Teachers, designers, and operators of electric motors, generators, and rotary converters are invited to send for "Modern Pyramids." This is a series of pamphlets containing practical suggestions on the performance, characteristics, operation, and application of carbon, graphite and metal-graphite brushes. Write National Carbon Co., Inc., Cleveland 1, Ohio, Dept. 15G.

★ BUY UNITED STATES WAR BONDS AND STAMPS ★

The trade-mark "National" distinguishes products of National Carbon Company, Inc.

NATIONAL CARBON COMPANY, INC.

Unit of Union Carbide and Carbon Corporation

Carbon Products Division, Cleveland 1, Ohio UCC New York, Pittsburgh, Chicago, San Francisco

ALLIS-CHALMERS 5/8% STEP REGULATORS GIVE YOU THESE OUTSTANDING ADVANTAGES:

Closer Regulation

Narrower Voltage Band — made possible with "Feather-Touch Control". By eliminating holding coils or holding-in magnets on the voltage control relay, voltage band can be narrowed down to take advantage of 5/8% steps; holding voltage within total band of ±5/8% or ±3/4 volts.

Lower Exciting Current

Need Only 1/3 The Exciting KVA required by older type regulators! Step regulators, in effect, release kva for other purposes, or reduce the burden of the generating and primary distribution systems.

Longer Contact Life

In 1933 Allis-Chalmers Introduced the *first* 5/8% Step Feeder Voltage Regulators. Their acceptance has grown until today 4,000,000 kva throughout the country is regulated by our equipment. Yet in this time not a single contact has ever been replaced due to deterioration under normal operation!

Fewer Bolted Connections

Exclusive Unit Construction eliminates 78 bolted connections. Both mechanism and transformer can be removed or placed into tank *as a unit*... without disconnecting leads or removing terminals!

Minimum Maintenance

The Quick-Break Mechanism, one of the main reasons for low contact deterioration, changes taps with a snap... yet comes to a quick stop without shock. No brakes or sealing-in switches are needed. Permits complete oil-immersion of all moving parts, keeping them dust-free, automatically lubricated!

♪ *Tune in the Boston Symphony, Blue Network, every Saturday at 8:30 pm, EWT.*

A 1695

INSULATION TESTED QUICKLY & ACCURATELY BY U.S. RUBBER CO., WITH L & N INSTRUMENTS

A cable-testing department which features convenience and safety, as well as accuracy, is shown in these views of a United States Rubber Company test area at Bristol, R. I. The test being conducted is ASTM Spec. D-257-38, "Methods of Test for Insulation-Resistance of Electrical Insulating Materials".

Reels of cable are immersed in tanks below floor level, and are reached by means of the cat-walks. In the test booth each operator is seated before a No. 5602-A2 Guarded Insulation-Resistance Test Assembly, to which leads are run from the exposed ends of the cables. Instruments are thus protected against the dust and dampness of the cable-handling area, yet the members of each test team can see each other at all times and testing proceeds with orderly speed and precision.

Features of Test Assembly

Each Assembly consists essentially of the Test Set, the Galvanometer and galvanometer-reading Lamp and Scale. The Test Set is shown here mounted flush in the table; the Galvanometer is on the timber post which rests on a pier independent of the building foundation.

In using the Set, the operator impresses the test voltage (max. 500 v) first on the Set's tenth-megohm standard resistor and then on the insulation; the galvanometer deflection is noted in each case and the insulation resistance computed therefrom. A guard circuit shunts all leakage currents around the galvanometer, so that only the current through the insulation can cause deflection, and no further precaution against leakage is required. Humidity has no effect, except on the dielectric under test. The Set contains an Ayrton shunt, for making the extent of galvanometer deflection convenient for the particular cable under test.

This Assembly differs from earlier ones in having no exposed switch contacts and in replacing the 2500-f Galvanometer (sensitivity 0.0001 μa; period 14 secs) with a No. 2500-b Galvanometer, whose sensitivity of 0.0005 μa is ample for routine tests and whose period is only 6 secs, thus greatly increasing the speed of operation. For the higher sensitivity required in research, the No. 2500-f Galvanometer is of course still available.

We will be glad to send further information regarding measurements under specific conditions.

Jrl Ad E-54-480(6)

A Slogan For Every American

LEEDS & NORTHRUP COMPANY, 4902 STENTON AVE., PHILA. 44, PA.

LEEDS & NORTHRUP

MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

The ONLY Resistors wound with *CERAMIC INSULATED WIRE!

A MAJOR RESISTOR IMPROVEMENT

The outstanding superiority of Sprague Koolohm Resistors in practically every important characteristic could—and did—result only from an entirely different engineering approach to basic problems—from the wire up. Research proved that the resistor was no better than the insulation on the wire. Koolohm ceramic insulation applied to resistance wire permitted such valuable engineering features that, in less than four years, these resistors have set higher standards of performance on hundreds of the most exacting applications. Standard units include 5- to 150-watt power types, bobbin types and meter multipliers. Write for Catalog—today!

SOLVING PROBLEMS of

UNWIELDY SIZE
REDUCED WATTAGES
CHANGED VALUES
HIGH AMBIENTS
MOUNTINGS
SHORTS
...and many more!

SPRAGUE ELECTRIC CO.
(Formerly Sprague Specialties Corp.)
RESISTOR DIVISION
NORTH ADAMS, MASS.

ARMY E NAVY

SPRAGUE KOOLOHM RESISTORS

KEEPING UP WITH

Electricity

ORDNANCE SPELLS IT F-U-Z-E, when referring to the mechanical device that keeps bombs safe to handle, but sets them to detonate on impact. If bombs are to be both safe and effective, fuze-timing must be accurate to a split second. To test them, Westinghouse engineers designed a new miniature wind tunnel, in which a blast of compressed air simulates speeds up to 800 miles an hour. A photoelectric cell device checks the timing to one one-hundred-twentieth of a second.

NEW FLUORESCENT DEVELOPMENTS include a *cold cathode* tube that lights up instantly; a new type of starter that eliminates blinking of fluorescent lamps; and a bulb so tiny that it can operate for several weeks on power from a single dry cell.

TOO GOOD. A short time after a large non-condensing turbine was placed in service by a large industrial company, the designer was called back to do further work in it. Reason: it was *too* efficient! Temperature of the exhaust steam was too low for plant process work. Machine is now operating with a satisfactory degree of inefficiency.

HEIGHT BY LIGHT is the basis of a device that is making flying safer. A beam of light from a 16-inch searchlight locates cloud layers; using an alidade (similar to a sextant) an observer sights the bright spot made by the beam. By triangulation, the height of the clouds can be calculated exactly in a matter of seconds, and this ceiling height is then radioed to the planes in the vicinity.

NEW HURRICANE is now in service with Boeing Aircraft Company. Westinghouse has just installed an 18,000 horsepower electric motor to drive the multi-bladed fan in Boeing's new wind tunnel. One of the largest operated by a private aircraft manufacturer, the new tunnel will be able to test airfoils, etc., at speeds up to 700 miles an hour.

When .0001 inch = 1000 hours

Problem: To provide an air-tight joint where the insulated connectors of an airplane radio vibrator project through the metal shell. (Vibrator contacts disintegrated in *ten hours* at high altitudes, when shells were not air-tight.)

Westinghouse research engineers were ready with the answer—a method of *soldering* metal to porcelain.

The porcelain piece is painted with a solution of gold and platinum and is then fired. This reduces the metal to a firmly adhering glaze, which is coated with a flux and tinned for soldering.

This gold-platinum film—barely one ten-thousandth of an inch thick—is the reason radio vibrators today last as long as the plane.

Solder Seal is the only known method of completely and permanently hermetically sealing a porcelain-to-metal joint. It is another example of Westinghouse leadership in every phase of electrical development.

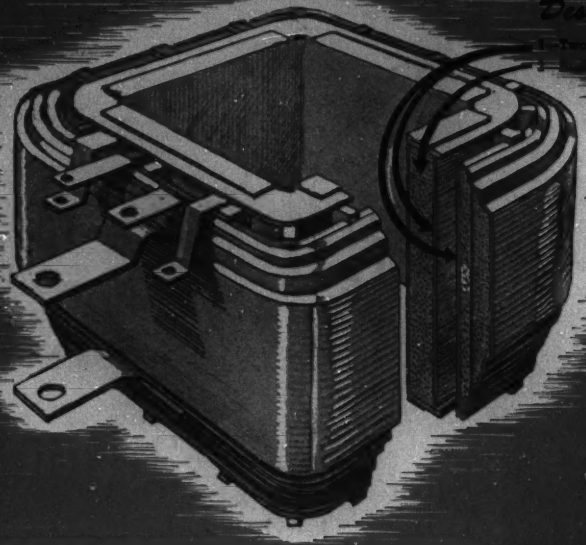
Westinghouse Electric & Manufacturing Company, Pittsburgh 30, Pennsylvania.

WESTINGHOUSE PRESENTS: *John Charles Thomas, Sunday 2:30, EWT, NBC. "Top of the Evening," Mon. Wed. Fri. 10:15, EWT, Blue Network*

Westinghouse

PLANTS IN 25 CITIES OFFICES EVERYWHERE

6 MONTHS COIL LIFE INCREASED TO 5 YEARS and still going!



Designed for the Job!

1—Two new heat radiating surfaces

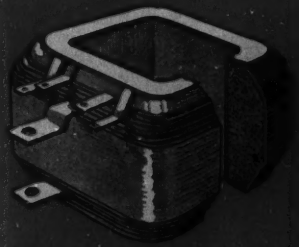
2—More efficient winding

The trouble: Steady overloads, frequent mechanical shocks and high current peaks caused field coil burn-outs every six months or so.

Our solution: By a complete coil redesign we more than doubled the heat radiation surface (see arrows at No. 1 above); by changing turns and wire size we reduced PR loss 11% (see arrow at No. 2 above).

The customer, a large cement manufacturer, writes: "In 1939 your field coils were installed in one of our shovels. Before that we had used as high as two sets per year on the crowd generator of this one shovel. It wasn't so much the cost of replacing the burned out coils, but to have one of the shovels out of operation really upset the apple cart. Since installing your field coils on each of our shovels we have had no coil trouble."

The difficulties faced by these coils are expressed in one sentence by the user: "Sometimes when the rock face is not blasted thoroughly the shovel bucket breaks its way through this limestone wall moving large pieces of solid rock, often larger than the bucket itself."



Conventional Coil . . .

Only slight visual differences distinguish the field coil pictured here from that shown above, which we engineered to meet the needs of its specific task. But—previous life averaged 6 months; now 5 years' identical use has not broken down the new coils. Clearance were integrated and balanced so that magnetic characteristics remained unchanged and ample clearances were maintained.

NATIONAL ELECTRIC COIL COMPANY

COLUMBUS, OHIO — BLUEFIELD, W. VA.

ELECTRICAL ENGINEERS: MAKERS OF ELECTRICAL COILS AND INSULATION— REDESIGNING AND REPAIRING OF ROTATING ELECTRICAL MACHINES

Selenium Corporation of America

Presents

The S. C. A. SELENIUM RECTIFIER

WITH

Dual SEALED-IN* ELECTRODES

AN EXCLUSIVE S.C.A. DEVELOPMENT

ALL S.C.A. SELENIUM RECTIFIERS HAVE HIGHEST OUTPUT PER UNIT WEIGHT, UNLIMITED LIFE, CAN BE USED IN TEMPERATURES FROM −55° C TO +75° C AND REQUIRE NO MAINTENANCE

The S. C. A. Selenium Rectifier with the Dual Sealed-In Electrode offers:

Maximum contact area at increased pressure ● Added protection against moisture and corrosion ● Undisturbed electrical contact after application of surface coating Permanence of rectifier characteristics and full plate efficiency ● Increased field of applications ● Shock and vibration-proof operation ● Complete interchangeability with all conventional selenium rectifiers

**Available only in S.C.A. Selenium Rectifiers. Trade Mark and Patents Applied For*

SELENIUM CORPORATION of AMERICA

1719 WEST PICO BOULEVARD • LOS ANGELES 15, CALIFORNIA

A Good Firm

to Connect With

BRITISH PLUGS

C.C. #50.343-1
British Ref. #10H-418
Signal Corps #PL-Q170

C.C. #50.397-1
British Ref. #110H-1191
Signal Corps #PL-170

C.C. #50.346-1
British Ref. #10-H-417
Signal Corps #PL-P170

Connector Corporation

401 NORTH BROAD ST., PHILADELPHIA, PA.

ELECTRICAL ENGINEERING

Registered United States Patent Office

JULY
1944

The Cover: A mobile steam power plant of 3,750-kva capacity, one of a number of such units being constructed in the United States for shipment to war-devastated areas.

American Car and Foundry Company Photo

Fluorescence Aids Mining ..... H. T. Plumb. . . 243

Fluorescent Lighting of Aircraft Instruments ..... A. D. Dircksen. . . 247

Control Devices for Voltage Regulators ..... AIEE Subcommittee. . . 250

A Physical Conception of Motor Operation ..... Robin Beach. . . 254

Electrical Engineering in the Postwar World—III ..... C. W. Kellogg. . . 264

Miscellaneous Short Items: Electronic Graphical Symbols Standardized, 246
Pennsylvania Trains Adopt Telephones, 266

Institute Activities . . . 267

Of Current Interest . . . 274

TRANSACTIONS SECTION

(Follows EE page 280; a preprint of pages 501–48 of the 1944 volume)

Controlled Rectifier Circuits ..... P. T. Chin, E. E. Moyer. . . 501

Design of Variac Transformers ..... Eduard Karplus. . . 508

Prevention of Deformation on Turbogenerators ..... John G. Noest. . . 514

Blast-Tube Cooling for Aircraft Generators ..... Cyril G. Veinott. . . 520

Manufacture of Aircraft Generators ..... F. M. Potter. . . 525

Behavior Factors of Rectifier-Driven D-C Motors ..... Victor Siegfried. . . 530

Three-Phase Aircraft Inverters ..... Sydney Wimpie. . . 532

Vibration Protection for Rotating Machinery ..... R. L. Webb, C. S. Murray. . . 534

Transmission-Line Constants ..... C. A. Streifus, C. S. Roadhouse, R. B. Gow. . . 538

Outdoor Oil Circuit Breakers ..... L. J. Linde, E. B. Rietz. . . 543

Temperature Standards for Industrial-Control Coils ..... B. W. Erikson. . . 546

G. Ross Henninger
Editor (on leave)
Floyd A. Lewis
Acting Editor
F. A. Norris
Business Manager
H. A. Johnston
Advertising Manager

Statements and opinions given in articles and papers appearing in *Electrical Engineering* are the expressions of contributors, for which the Institute assumes no responsibility. ¶ Correspondence is invited on all controversial matters.

Published Monthly by the

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Founded 1884

NEVIN E. FUNK, President H. H. HENLINE, National Secretary

VOLUME 63
NUMBER 7

PUBLICATION COMMITTEE: H. H. Race, *chairman*; C. E. Dean; F. Malcolm Farmer; H. H. Henline; K. B. McEachron; John Mills; F. H. Pumphrey; C. F. Wagner; S. B. Williams

Electrical Engineering: Copyright 1944 by the American Institute of Electrical Engineers; printed in the United States of America; indexed annually by the AIEE, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Address changes must be received at AIEE headquarters, 33 West 39th Street, New York 18, N. Y., by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge.

ONE ALWAYS STANDS OUT

IT'S THE QUALITY OF PERFORMANCE THAT COUNTS

Vol.
1944

ALSIMAG

TRADE MARK REGISTERED U. S. PATENT OFFICE

STEATITE CERAMIC INSULATORS

ARMY E NAVY

There are many dancers in the ballet but only one Premiere Danseuse. It's the quality of performance that counts . . . the exquisite skill and precision that is acquired only through long years of training and experience.

One always stands out! Among insulators it's ALSIMAG.

ALSIMAG Steatite Ceramic Insulators are the result of 42 years of Leadership in the ceramic field. The knowledge, skill and precision gained from these years of experience is your assurance of the quality of ALSIMAG performance.

AMERICAN LAVA CORPORATION
CHATTANOOGA 5, TENNESSEE

42nd YEAR OF CERAMIC LEADERSHIP

ELECTRICAL ENGINEERING
VOLUME 63, NUMBER 7 JULY 1944

Fluorescence Aids Mining

H. T. PLUMB
FELLOW AIEE

Ultraviolet light and fluorescence are useful aids in the mining industry. This engineer describes their general uses and limitations, and explains the theory of fluorescence in simple terms without resort to complicated mathematical or physical details.

FLUORESCENCE is a smart way of saying "fluorspar luminescence." Ninety years ago the great mathematical scientist, George Gabriel Stokes, was doing a chemical experiment with fluorite, when accidentally the rock came into view of an arc lamp. Stokes noticed the color of the crystals change suddenly from green to blue. His keen mind went to work on that trivial observation.

Fortunately he was not only a smart physicist and chemist, but a brilliant mathematician. For many years he studied this experiment and eventually evolved Stokes' law of fluorescence. He found that fluorescent light is emitted at a lower frequency and longer wave length than the exciting light; hence fluorescent colors, to be visible, usually require excitation from an invisible light of higher frequency, such as ultraviolet, cathode rays, or X rays. Blue or violet visible light may cause green, yellow, or red fluorescence, or may even produce fluorescent infrared rays which are invisible.

THEORY

Fluorescence, or photoluminescence by exposure to invisible radiations, is entirely different from colors seen by ordinary light reflection or transmission. Reflected light has the color or frequency that was in the original light, just as an echo of sound has the same pitch as the original sound waves. Fluorescent color is independent of the surface color caused by ordinary visible light. The phenomenon may be due to atomic resonance or "sympathetic vibration" of electrons within the molecules.

Fluorescence depends on the chemical or atomic molecular structure of the material which fluoresces. Each atom has electrons revolving in certain orbits or potential levels. The outer electrons may be elevated to other orbits normally vacant. There are potential levels about the nucleus of every atom much like gravitational levels about the earth, or like planetary orbits about the sun. If the electrons within an atom are arranged so that one of these can vibrate freely at a certain higher frequency, then by resonance it may absorb energy from a high-frequency exciting light source and temporarily revolve in an orbit with higher energy. When it falls back to its normal orbit, the extra energy which it received will be reradiated as light, but of a lower frequency or different color from the exciting ray.

Stated again in a different way, when a quantum bullet (energy photon) of high-frequency light collides with an electron vibrating peacefully in its normal place, the electron may be knocked to some other level farther from the nucleus of the atom. Whenever the electron falls back to its normal level, the increased energy which it received from the photon is reradiated as light, but generally at a lower frequency than the original light beam. Apparently the electron cannot absorb all the energy of the photon; otherwise the reradiated energy would have the same color.

The reradiated energy is the difference in total energy between the atom or molecule which is excited and that which is not excited. The amount of this energy is directly proportional to the frequency or color of the reradiated light. A scientist named Planck wrote the law thus:

$$E = E_{ex} - E_n = hf$$

where E is the reradiated energy, E_n is the normal energy of the atom, E_{ex} is the total energy of the atom when excited to the higher level, h is Planck's constant, and f is the frequency of the reradiated light.

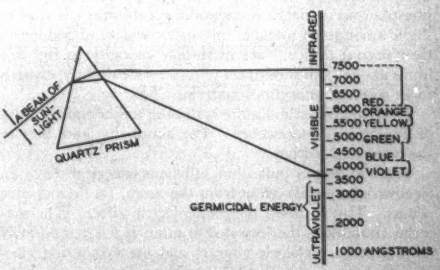


Figure 1. Schematic diagram of sunlight spectrum, showing the range of wave lengths of infrared, visible light, and ultraviolet energy

If the displacement is instantaneous only and ceases immediately with the excitation, the phenomenon is called fluorescence. If the displaced electrons do not all immediately return to their normal places, but do so gradually, the emission is called phosphorescence. The displaced electron may fall back in a single movement or

H. T. Plumb is a consulting engineer, Salt Lake City, Utah.

Essential substance of a paper presented at the AIEE national technical meeting, Salt Lake City, Utah, September 3, 1943.

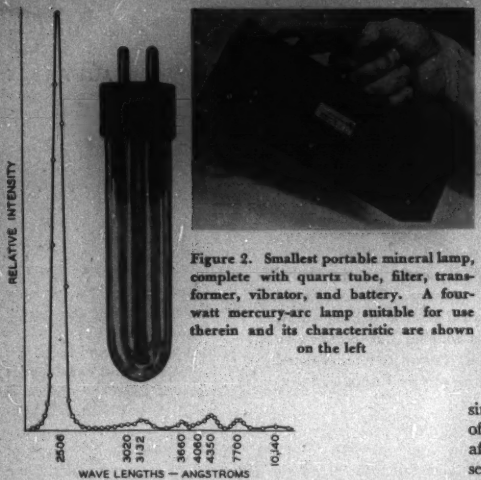


Figure 2. Smallest portable mineral lamp, complete with quartz tube, filter, transformer, vibrator, and battery. A four-watt mercury-arc lamp suitable for use therein and its characteristic are shown on the left

hesitate at an intermediate level. A baseball batted high into the air will give a rough illustration of this. The ball is pushed to a higher gravitational level above the earth by energy from the bat. It does not stay at the new level but falls to its original level. Not all of the energy received from the bat is returned to the catcher's hands; some is lost enroute. Losses may lower exciting energy so that the energy is reradiated at a lower frequency.

The returning ball may be held for a time in the top of a tree, or at some intermediate level. This temporary delay may help us understand phosphorescence. The phosphorescent delay in crystalline substances is due to slight amounts of metallic impurities which, imbedded in the "crystal lattice," act in similar capacity to the tree limbs above. All substances phosphoresce slightly, crystals more so than amorphous material.

There are other and more confusing mathematical ways of explaining fluorescence. For simplicity and brevity these are omitted here.

When a photon bullet has sufficient energy to force an electron completely away from the atom, no fluorescence occurs. This is called the photoelectric effect. The material containing the incomplete atom is left temporarily with a positive electric charge, and the wandering electron will bring a negative charge to whatever it contacts.

We have been explaining this theory as though there was only one bullet hitting one electron. Actually the ultraviolet source is pouring out a barrage of bullets at various frequencies. Some of the lower-frequency shots may be effective; some of the higher-frequency shots may be effective; but the most effective results will come from a certain definite frequency. Each material will fluoresce best for one certain frequency of incident light. Increasing or decreasing the incident wave length tends slightly to increase or decrease the fluorescent wave length. But this frequency relationship is not a simple fixed numerical ratio such as octave or harmonic. Every substance has its own arrangement of molecules, atoms, and electrons, and, therefore, its distinct tone or response frequency, much as each string in a piano is tuned differently and will resound to a different frequency.

The fluorescent response of a material may be a single frequency or color, or a mixture of several bands of color, or a continuous spectrum of all visible colors affecting the eye as white light. The eye averages all its sensations into one composite color. Spectographic analysis would give separate information with each line in the fluorescent spectrum.

It is well to remember that the human eye is a very limited detector of light. The best eye can see only one octave of color while sunlight contains many octaves. This indicates how color-blind we really are. Substitute photelectric eyes with high-power amplifiers in place of the human eye and the vast range of fluorescent colors with which to detect an infinite variety of chemical combinations becomes apparent.

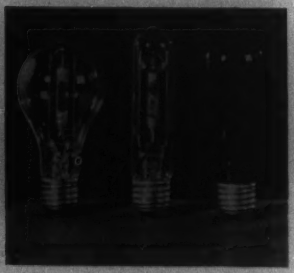
It is interesting and important to tabulate the wave lengths and vibration frequencies of various colors and radiations. A few of these are given in Table I. The limits stated are approximate but close.

CHEMICAL ANALYSIS BY FLUORESCENCE

Analyzing rocks, minerals, and chemicals by fluorescence is not yet an exact science, or rather it is too complicated a mathematical study for beginners. Very slight amounts of chemical impurities may permit or prevent fluorescence, or may change entirely the color emitted. Similarity of color does not guarantee the same chemical content; important determinations should be checked by chemical assays. Temperature effects fluorescence and phosphorescence. Pure metals seldom fluoresce; organic materials usually fluoresce.

TYPE OF LAMP

Now as to the type of lamp best suited to the work in hand. Enormous quantities of ultraviolet light, which may



A B C

Figure 3 (left). High-pressure 100-watt mercury-arc lamps for laboratory and home use

A. S-4 sunlamp, with Corex glass outer globe
B. AH-4, with plain glass outer globe
C. BH-4, with ultraviolet filter globe

Figure 4 (right). Viewing box for daytime examination in the field making use of a portable lamp

Table I. Electromagnetic Waves

	Frequency (Trillions of Cycles Per Second) (10^{12})	Wave Lengths	
		Angstroms (A)	Microns (μ)
Infrared rays			
Longest wave	1	3,000,000	300.
Shortest wave	400	7,500	0.75
Visible light			
Red	400	7,500	0.75
Violet	750	4,000	0.40
Ultraviolet rays			
"Near ultraviolet"	750	4,000	0.4
to	1,000	3,000	0.3
"Middle ultraviolet"	1,000	3,000	0.3
to	1,500	2,000	0.2
"Far ultraviolet"	1,500	2,000	0.2
to	3,000	1,000	0.1
X rays			
Longest wave	3,000	1,000	0.1
Shortest wave	30,000,000	0.1	0.00001

excite fluorescence, reach the earth's outer atmosphere. But air is a poor conductor of high-frequency light, and therefore, at the earth's surface sunlight contains very little short-wave ultraviolet. The author has a portable daylight device for examining specimens in the field. It works well for materials which fluoresce with low frequency ultraviolet. Fortunately, men have learned how to build arc lamps which produce an abundance of higher-frequency light. These mercury-vapor "sun lamps" are available for health purposes and for many commercial uses. Used with special glass filters which absorb the visible rays, they are powerful sources of invisible light with which to study fluorescent materials.

MINING

In prospecting for minerals it is necessary to use very high-frequency ultraviolet light from a mercury arc enclosed in a quartz tube. Ordinary glass is not transparent to high-frequency light. An electric arc in low-pressure mercury vapor is rich with invisible high-frequency rays, but it is bright with visible light. Hence there must be a special filter to remove as much as possible of the visible light. The chief difficulty lies in securing a filter glass which will remove the visible light without also stopping the high-frequency ultraviolet rays. The best glass filter available is Corning 986, which transmits from visible violet up to about 2,537 angstroms, or the center of "middle ultraviolet." This will fluoresce willemite and scheelite and also pass erythematous health rays and some germicidal rays.

Most commercial lamps have imperfect filters which pass too much visible and not enough of the very-high-frequency light. This may result in poor tests due to color confusion. High-pressure lamps give more high frequency if the outer glass globes are removed.

Different materials which fluoresce the same color may require widely different excitation frequencies. Recognizing this important fact, the author has invented a test lamp which radiates two or more beams of different frequencies. This lamp makes the determination of ores, such as scheelite, more precise and makes it possible to avoid expensive errors. If such a lamp cannot be secured, and one is using a high-frequency lamp which fluoresces scheelite, check further with some low-frequency lamp such as the Purple-X incandescent lamp.

The test lamp should be used in total darkness, at night or in a dark room. Time should be allowed for the human eye to become sensitive to the dim light of fluorescence. When visible light is used it also should be dim and shielded to avoid glare. Avoid looking directly into the ultraviolet light, as it may be harmful to the eyes.

Whenever possible it is best to bring specimens to a high-power lamp operating from a 120-volt a-c transformer. When this is not feasible, a smaller portable lamp, with battery-operated vibrator, may be taken to specimens in the field. Prospecting with fluorescence is new and often misinterpreted. However, good lamps, are not too expensive, they give immediate results and have become very popular aids in prospecting, mining, and milling.

Table II. Utah Minerals Which Fluoresce

Name	Location	Colors* by Fluorescence	Colors* by Phosphorescence
Agate	Jericho, Joy, Topaz, gen.	Y., G.	
Alabaster	S.E. and gen.	Y. W.	W.
Alunite	Marysville	Pale W.	
Aragonite	Abundant, gen.	Y., W., R.	W.
Autunite	Eastern Utah, Parla	Y., G.	
Barite	Green River, Tooele	Y., W.	W.
Calcite	Pelican Pt., gen.	P., R., Bl.	R., W.
Calamine	Tintic, gen.	Y., G.	
Cerussite	Park City, gen.	Pale Bl.	
Chalcedony	Joy, Topaz Mt., gen.	G., Y.	
Cinnabar	Mercur, Wash. Co.	Mercury shadows	
Coal	Carbon Co., gen.	Every color	Every
Jasper	San Rafael, Green River, Joy	G., Y.	
Cuprotungstate	Gold Hill	Y.	W.
Dolomite	Gen.	Bl. W.	
Elaterite	Uinta Basin	Br.	
Flint	Gen.	Y., G.	
Fluorite	Drum Mts.	Bl.	W.
Gypsum	Eureka, gen.	G.	
Halite	Redmond	Slightly R.	
Hydrozincite	Hidden Treasure	Bl., Y., Pur.	
	Horn Silver Mine, gen.	Bl.	W.
Limestone	Gen.	W., Y., Bl.	Y., W.
Lime incrustations	Grouse Creek, gen.	Y., W., Bl.	Same
Marble limestone	Gen.	Various colors	W., Y.
Opal	Gold Hill, Topaz, Alta	G., Y., W.	
Opalized wood	Gen.	Various, G.	
Petrified wood	Heber, Wayne Co., gen.	Y., R., G.	
Petroleum	Wash. Co.	Bl.	
Powellite	Milford Dist., Alta, gen.	Y., O.	Y.
Quartz geode	Green River	Bl., W.	W.
Incrusted crystals	Park City Mines	R.	
Scheelite	Alta, Box Elder, gen. Lucin, Gold Hill, Milford, W. Tintic	Bl. W.	
Scheelite and molybdenum	W. Tintic, Gold Hill	Golden cream	Y., W.
Siderite	Newhouse	Pale Bl.	
Sphalerite	Beaver, Park City	Bl., bright gold	
Smithsonite	Hidden Treasure	G.	G.
Stalactites	Caves	Light Y.	Same
Travertine	Monida, Toplift, gen.	Y., Br.	Y.
Tungstite	Gold Hill		
Willemite	Milford, Talisman	G.	W.
Willemite and mimetite	Beaver Co.	Pale Y., R.	Same
Wollastonite	Gen.	Y.	
Zoisite	Mineral Range	Pur., Y.	
Zoisite with scheelite		Bl. spots	
Zippeite	So. Utah	Brilliant Y., G.	

* Abbreviations used in table are: Gen., general; Y., yellow; G., green; W., white; R., red; P., pink; Bl., blue; Br., brown; Pur., purple; and O., orange.

ROCKS WHICH FLUORESCE

We have tested many Utah minerals. Those which fluoresced are listed in Table II, with the colors of the reradiated light and the places where found. Of course the list is not complete and will be amplified by further tests.

Similar rocks from other states, for the most part, fluoresce in the same general way. The fluorescent colors

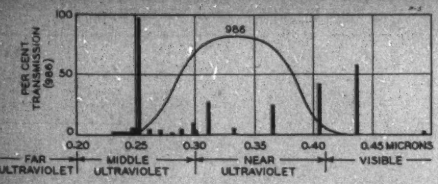


Figure 5. Relative intensities of mercury lines before transmission through tubes and by Corning 986 filter glass

vary with the chemicals contained in each specimen and, therefore, with the locality, and somewhat with the type of lamp used. Too much or too little of an impurity may totally prevent fluorescence. Colors emitted from a specimen by fluorescence and phosphorescence often are entirely different.

THE FUTURE

Chemical analysis which depends on the human eye for measuring fluorescence is only approximate, and yet it has accomplished marvels. Whenever laboratories begin to analyze the fluorescent colors by spectroscopy and to measure their intensity with a photoelectric device, the results will be a thousand times more accurate. Then, qualitative and quantitative analysis by fluorescence will be far more valuable than now. Then, every change in wave length, brilliance, and purity of fluorescent color will interpret the atomic mysteries within complicated materials.

Electronic Graphical Symbols Standardized

Prior to 1918 only a few vacuum tubes of a simple type, usually a glass envelope enclosing a filament, a plate, and a control grid, were in use. Recently, especially in the war program, they constantly are being applied in new fields and the demands of the Armed Forces, particularly for communication and electrical detecting devices, have accelerated their use to an unprecedented degree. Even in civilian life the expansion will be noticeable: four or more types of tubes now will be used in every home radio receiver and in manufacturing processes many types of control equipment incorporate electronic devices.

As a result electronic devices have become so complicated in structure that simple picturization on drawings is no longer feasible. For this reason an approved American Standard Z 32.10-1944 co-ordinating and standardizing graphical symbols depicting electronic devices on drawings has just been completed by a committee working under the sponsorship of the AIEE and The American Society of Mechanical Engineers. In the new Standard the graphical symbols for electronic devices have been made a study in themselves, for, although they always are used as a part of power or communication circuit drawings, the devices really belong to a distinct class.

In the Standard, the symbols for the tube components are followed by typical applications showing their use in various classes of devices such as the thermionic, cold-cathode, and photoemissive devices of varying structures and combinations of elements as triodes, pentodes, cathode-ray tubes, magnetrons, and velocity-modulation tubes. To formulate a symbol for any specific tube, the components are selected from the list given or are made by the assembling of component symbols.

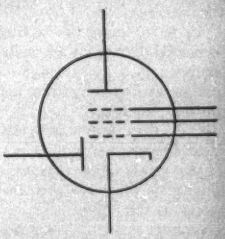


Figure 2. This simplified diagram of a diode-pentode with pentode amplification added to the tube is representative of those recommended by the new Standard

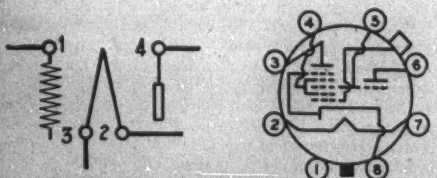
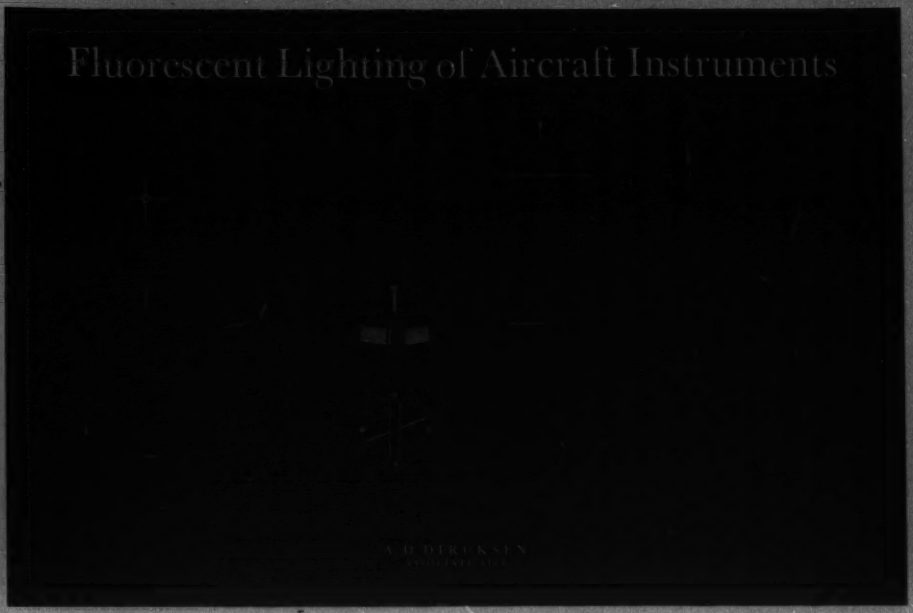


Figure 1. At the left is a typical picturization of a 1916 model of an amplifier tube. Represented by the resistor symbol, the grid was supposed to depict the resistance of the flow of electrons from the cathode to the plate, the former being the simple filament type and the latter a simple surface. The tube envelope is not even represented. On the right, a triode-heptode with rigid envelope connections and basing information becomes quite a complex diagram of connections when all this information is shown

The symbols for electronic devices are intended primarily to indicate only electrical functions, although their respective physical pattern may be indicated in some cases where basing diagrams are required. In general the physical relation of component parts of a piece of apparatus appears as far as possible without undue complication of the symbol or drawing.

Symbol sizes and line widths as depicted in the Standard have been designed for average drawing use and, when reduced two to one, result in sizes which seem most desirable for publication. The size and width of lines may be altered as required, although it is believed that the sizes shown in the Standard are the best possible for general usage. Wires need not be brought into the symbol in any particular position but may be varied as required to simplify the wiring pattern in a specific circuit drawing.

Fluorescent Lighting of Aircraft Instruments



Lighting of instruments in airplanes by the use of indicator markings that fluoresce when bathed in ultraviolet radiation is one of the latest developments that adds to the convenience and safety of the crew. The light is not detectable by enemy airmen, does not cause unwanted reflections, and does not impair night vision. Through several stages of development, a blue fluorescent mercury-vapor lamp which operates on the 24-volt d-c system of the airplane has been produced for generating the ultraviolet radiation.

INSTRUMENT ILLUMINATION by ultraviolet flood lighting is the use of near ultraviolet rays to activate the fluorescent and luminous markings on aircraft instruments to produce a uniformly illuminated instrument panel with no apparent visible light in the cockpit. Ultraviolet radiation also is called "black light" commercially.

The radiation used in this application is in the near ultraviolet region which is just below the visible portion of the light spectrum. It may be obtained from blue fluorescent, argon glow, and mercury-vapor lamps, and also from incandescent lamps operated at a high filament temperature which produces high light output at the expense of short lamp life. Of these lamps, the most efficient source for this radiation is the blue fluorescent lamp with a special blue phosphor powder.

The fluorescent instrument lighting system, including the blue fluorescent lamps, the lamp assemblies, and related operating equipment (including the vibrator inverter), has been developed by the Engineering Division, Wright Field, in conjunction with the lamp and fixture manufacturers.

A. D. Dircksen is a major in the United States Army Air Forces, assigned to the electrical branch, engineering division, Matériel Command, Wright Field, Dayton, Ohio.

Essential substance of an address presented before the AIEE Dayton Section, February 2, 1944, in Dayton, Ohio.

Fluorescent ultraviolet instrument lighting replaced the unsatisfactory type of individual instrument lighting by direction of the Chief of the Air Corps (now Army Air Forces) in January 1940. Steps were being taken at that time for service test of the fluorescent ultraviolet lighting system. Accelerated comparative flight tests were conducted at Wright Field on the individual instrument lighting and lighting by ultraviolet radiation from argon and blue fluorescent lamps. The fluorescent system was by far the best as the near ultraviolet radiation obtained from the blue fluorescent lamps was in excess of that required for the worst conditions of dawn and dusk. Because of this property of the lamp, a dense ultraviolet filter was used to eliminate nearly all traces of visible light in order to permit operation in a cockpit of practically total darkness so as to improve the dark adaptation of the crew for night operation and to minimize reflections in the windshield and canopy. The argon lamp, with thin ultraviolet filter, provides insufficient radiation to produce clear and well defined numerals, and unless placed very close to the instruments adds little to the original brightness of the self-luminous material. The self-luminous material (greenish color) has been changed to orange fluorescent material in order to improve the dark adaptation of the crew for night operations. However, a few

navigational instruments retain limited markings of self-luminous material (orange) for safety in case of failure of the lighting or electrical systems.

The blue fluorescent lamp is a mercury-vapor lamp which has a coating of fluorescent material on the inside of the bulb. This coating transforms the short ultraviolet rays of 2,537 angstroms to near ultraviolet rays of a wave length of 3,650 angstroms. The radiation emitted from the blue fluorescent lamp assemblies, with the ultraviolet-light transmitting filter glass, is of the near ultraviolet light, as shown by curve *A* of Figure 1, and is not injurious to the eyes or skin. The harmful ultraviolet rays are absorbed by the glass bulb of the lamp and the filter. The emission of the blue fluorescent lamp alone is shown by curve *F* which peaks at 4,400 angstroms and the filter peaks at approximately 3,650 angstroms, at which value the fluorescent material used for the dial and pointer markings functions most efficiently.

The near-ultraviolet rays emitted from the lamp assemblies are harmless; however, the assemblies should be mounted between the operator and the panel and directed so that none of the direct rays reach the eyes of the operator. These rays may cause fluorescence of the eyeballs resulting in discomfort and temporary impairment of vision which destroys dark adaptation and appears as a light fog; however, no ill affects will result. With the lamp assemblies properly mounted and directed toward the instrument board there is no discomfort or annoyance to the operator but a pleasing uniformly illuminated instrument panel. The reflection of near-ultraviolet radiation from the dark-colored instrument panel and cockpit is practically negligible. Extensive flight tests indicate no eye strain or discomfort when compared to other types of instrument lighting.

DEVELOPMENT OF THE FIRST SUCCESSFUL LAMPS

Because of the necessity for locating the lamp assembly between operator and instrument panel, it was not possible to use the standard 15-watt 18-inch 110-volt blue fluorescent lamp, and the lamp industry therefore was requested by the Matériel Command to develop a small 110-volt blue fluorescent tubular lamp. The result was designs for a four-watt lamp six inches long, and a six-watt lamp nine inches long. Only the four-watt lamp was standardized in order to minimize the number of types of lamps and lamp assemblies.

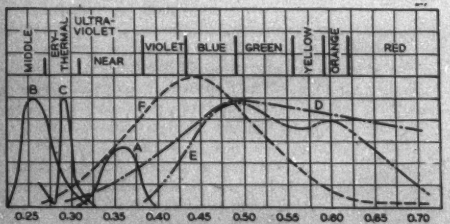


Figure 1. Relative amount of radiation from various sources in the ultraviolet and visible portions of the spectrum

A—Near-ultraviolet light passed by filter glass used with fluorescent lamp assembly
B—Germicidal lamp
C—Sun lamp
D—Daylight
E—Daylight fluorescent lamp
F—Blue fluorescent lamp

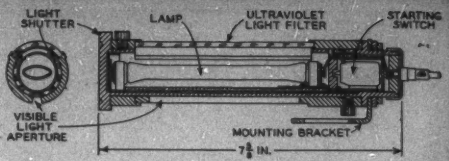
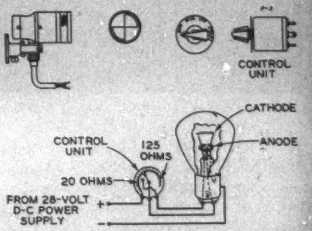


Figure 2. Fixed type of cockpit fluorescent lamp assembly for 110-volt a-c operation

After these lamps were developed it was necessary to obtain a suitable lamp ballast, which is a series choke coil to limit the lamp current to 145 milliamperes at 115 volts alternating current. It was also necessary to obtain a suitable neon-glow automatic-starting switch, and inverters to change 12- and 24-volt direct current to 110-volt alternating current for operation of the four-watt 110-volt tubular lamp. To reduce the inverter to minimum size and weight, the vibrator type was selected and designed for operation at a frequency of approximately 180 cycles per second, with the series choke coil incorporated in the transformer. A three-volt a-c output was also provided from a separate secondary winding on the transformer to provide a limited amount of three-volt power for the compass light, bomb indicator lamps, and miscellaneous three-volt lamps. If the airplane is already supplied with a 110-volt 400-cycle rotary inverter, the vibrator type of inverter is not required and is replaced by an auxiliary box, containing two or four (as required) 400-cycle choke coils to be connected in series with the power supply and the lamp assemblies. The system operates in a manner similar to the usual commercial 15- or 20-watt fluorescent lamps with self-starting switches of the neon-glow type.

Figure 3. Cockpit fluorescent lamp assembly for 24-volt d-c operation



The first fluorescent ultraviolet lamp assemblies standardized by the Army Air Forces were a fixed and a flexible type. The lamp housings of each lamp assembly are identical except a 12-inch flexible arm is supplied in the flexible type instead of a fixed bracket. The flexible lamp assembly is intended for use on fighter or single-cockpit-type airplanes that normally use a stick-type control, and when in use is placed approximately over the control stick to produce a uniformly floodlighted instrument panel. When not in use it is fastened, clipped, or pushed to the side of the cockpit. The fixed-type assembly is normally located on the control column, the underside surface of the light shield, the side of the fuselage, or the control pedestal. The lights should not be located overhead, but the light beams should be retained as much as possible under the instrument panel light shield and between the operator and the instrument panel. The lamp assemblies are designed also to produce selective visible

Figure 4. A 24-volt d-c fluorescent ultraviolet lamp with starting and on–off switches incorporated in the lamp assembly

light by rotating the lamp filter housing 180 degrees for illuminating maps and for floodlighting the cockpit, if desired, with visible (blue) light when flying by instruments in bad weather, and have included in the base the automatic-starting switch of the neon-glow type, which is designed so as to serve also as a connector receptacle. Figure 2 shows such a lamp assembly.

REDUCTION IN SIZE OF LAMP ASSEMBLIES

In some installations, difficulty was encountered in satisfactorily locating the lamp assemblies because of their size, so smaller assemblies were then developed in which the length was reduced and the diameter was reduced to approximately one half that of the first type as described in preceding paragraphs. These units were fabricated with a lamp housing and a lamp cartridge but did not include the visible light feature.

The lamp cartridge consists of a special fluorescent lamp comprising a tubular ultraviolet-light filter bulb, and a small neon-type glow switch connected to the lamp terminals, mounted in a metal housing which includes a series of holes and an aperture for the light shutter. To change the output, the knob on the end of the housing shell, which fits into a boss on the lamp cartridge, is turned to rotate the lamp cartridge to place the proper aperture in line with the aperture of the lamp assembly housing. The control switch is in the input circuit of the vibrator-type inverter.

LAMPS FOR LOW-VOLTAGE D-C OPERATION

The lamp industry was requested to develop a 24-volt d-c blue fluorescent lamp for operation directly from the standard 24-volt d-c electric system, thus eliminating the need for the vibrator inverter. The result was the present four-watt blue fluorescent lamp with indexing (polarized) bayonet candelabra base shown in Figure 3. At this time a new and more efficient phosphor was developed and used to obtain approximately the same light output as the four-watt, 110-volt lamp. It also became possible to simplify the four-watt 110-volt tubular lamp by using this new phosphor with a round instead of a flat bulb.

A small light-weight fixture was designed to house the new four-watt 24-volt lamp for use as a cockpit light. This unit is operated by a rheostat-type control unit that includes the series ballast (20 ohms) for the lamp, a dimming rheostat of 125 ohms, on-off switch, and manual starting switch. Dimming is accomplished by reducing the voltage on the lamp. The lamp assembly housing has a slotted filter arrangement to obtain selective visible and ultraviolet light by rotating the lens housing head. The control unit is so designed that the contact arm is held in the start position for a few seconds to heat the lamp filament and vaporize the mercury. The arc is made upon release of this starting switch by the spring pressure to the "on" position of the control unit.

The 24-volt four-watt blue fluorescent lamps provide uniform floodlighting that is not detectable by enemy aircraft with the least weight and power consumption of any lighting system heretofore used by the Army Air Forces.

STATUS OF CURRENT DEVELOPMENTS

A recent development, shown in Figure 4, proposes the use of an iris-type light shutter to reduce the light output from 100 per cent to zero instead of dimming by rheostatic control, which could not be complete lest the arc go out at approximately five per cent of maximum ultraviolet-light output. This type is designed to give selective visible and ultraviolet light by rotating the filter housing cap. A retractable cord has been developed for this light which will result in a minimum amount of free length of cord to foul the controls and permit hand operation of the light for reading maps and searching in the cockpit.

Tests are also being conducted on a self-starting lamp circuit using the standard four-watt 24-volt blue fluorescent lamp.

It is difficult to locate ultraviolet lamps in the bombardier's compartment that will illuminate the fluorescent markings of the bombsight, the fluorescent bombing tables and charts, and the instruments. Therefore, a suitable headband, which permits the bombardier to have free use of two hands, has been developed, for which a normal stowage position is located near the instrument panel to illuminate the instruments until the bombardier is required to operate the charts, bombing tables, and bombsight.

Accuracy of Control Devices for Feeder-Voltage Regulators

A standard for the specification of accuracy tolerance and for the establishment of accuracy classifications for voltage regulators is under preparation by the AIEE transformer subcommittee. This article, discussing the application and characteristics of such regulators, has been prepared in order that engineers interested in system design may be informed of the nature and effect of errors in the regulator control system.

THE transformer subcommittee of the AIEE electrical machinery committee has undertaken a study of the factors involved in the performance characteristics of feeder-voltage regulators in order to lay the ground work for preparing standards which this type of apparatus must meet to insure adequate performance. Because voltage regulators are important elements in most transmission and distribution systems, the transformer subcommittee felt that a discussion of their characteristics would benefit the industry.

GENERAL

The control equipment for feeder-voltage regulators consists essentially of a voltage-responsive relay called a "voltage-regulating relay" and a source of potential to indicate the voltage at the regulator output terminals. These serve to control the operation of the regulator so that the output voltage can be held at a desired value under certain predetermined conditions.

As an auxiliary to the voltage-regulating relay, there may be a "line-drop compensator" which simulates the voltage drop in the actual (or hypothetical) circuit being regulated. This voltage is approximately proportional to the line drop and is introduced in series with the regulator voltage applied to the control element. The regulator is thereby enabled to maintain desired voltages at points remote from the point of installation.

Other auxiliary devices may include time-delay relays, limit switches, control and protective relays of various kinds, and other equipment required to perform specific functions.

As the control voltage drops somewhat below the value for which the voltage-regulating relay is set, contacts are closed which energize some means for increasing the output voltage. Likewise, as the control voltage exceeds the value for which the relay is set, other contacts are closed which energize means for reducing the output voltage. The difference between the values of the control voltage, which caused the "raise" and "lower" contacts to operate, is known as the "relay band width." The magnitude of this band width affects the frequency with which the regulator functions, since the smaller the band width, the more operations will occur in holding output voltage within desired limits. If the band width is too small the regulator will be in almost continuous operation. In the case of step-voltage regulators, the voltage-regulating-relay band width must, of course, be somewhat larger than the voltage steps to prevent hunting or pumping. The relay band width of all regulators is adjustable.

This report, sponsored by the transformer subcommittee of the AIEE committee on electrical machinery (M. S. Oidacre, chairman), was prepared by a working group consisting of J. E. Clem, J. R. North, W. C. Sealey, and C. F. Wagner, chairman.

The effectiveness of the entire regulator is directly dependent upon the operation of the control devices and any inherent lack of accuracy in their component parts is of serious concern. Erratic performance of voltage regulators due to inaccuracies of their control devices may require excessive system investments to avoid unsatisfactory customer voltages and consequent customer complaints. One might also question whether errors in the control devices affect the availability of the full range of the regulator or limit the range of bus voltage over which satisfactory regulation is attainable. Before these questions can be discussed adequately, consideration must be given in some detail to the functional requirements of the regulator and its control device and the effects of inadequacies upon the system voltages.

SYSTEM CHARACTERISTICS

Even with a perfect regulator, the voltage along a distribution circuit would vary with location, loading, and time. It is recognized that some tolerance in voltage magnitude at the customer's service entrance must be allowed. The characteristics of utilization devices determine the allowable upper and lower limits of the design voltage spread.

Figure 1a is a schematic diagram of a typical distribution circuit. Figure 1b shows the voltage distribution throughout the circuit for light-load and full-load conditions. All voltages are given in terms of an equivalent 120-volt base. The full-load voltage allocations which are representative of accepted practice are eight volts drop in the feeders, three volts drop in the primary mains and laterals (feed point to primary of last transformer), four volts drop in the distribution transformers, three volts drop in the secondary, and one volt in the service. At extreme light loads, these voltage drops are assumed to be 25 per cent of their maximum value.

It should be noted that the desired full-load voltage at the first transformer is 125 volts, while the desired light-load voltage at this point is much lower, or slightly over 121 volts. The reason for this is that during the short period of primary-circuit full load, it is very desirable that the voltage on the primary side of the first transformer be held at a high value to compensate for the probable large drop in transformer, secondary, and service, while during the many hours of the day and the season of the year when the primary-circuit load is appreciably less than the maximum value, it is equally desirable that the voltage at the first transformer be held at a lower value to prevent undue shortening of the life of lamps and many other devices which are normally in use for long periods during the day. Peak loads on a distribution circuit are of very

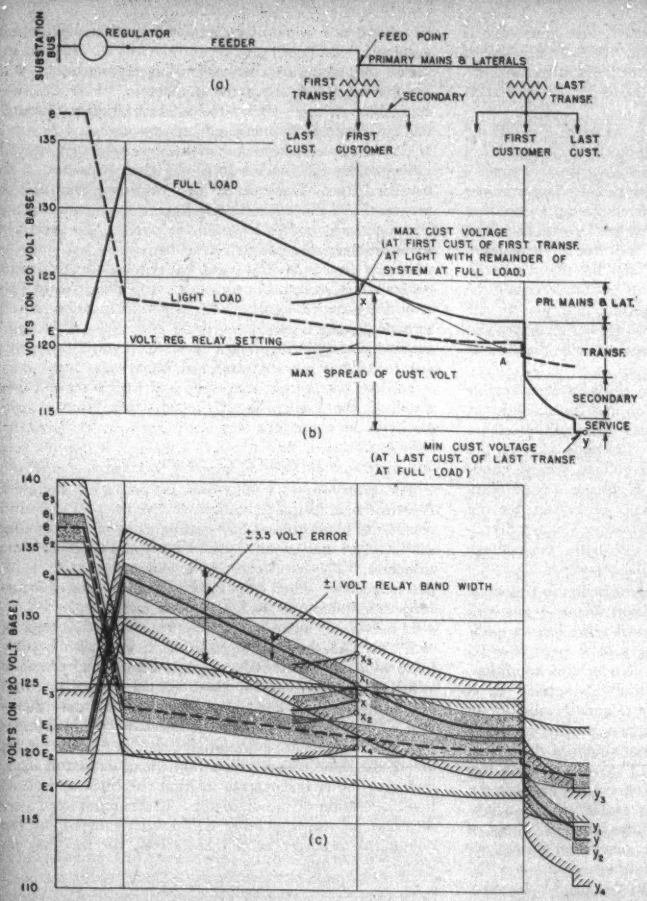


Figure 1. Effect of control-device error upon voltage along distribution circuit

short duration and exist only a few hours during the year. It is equally important not to let the utilization voltage become too low during the short peak period or too high during the very long off-peak period.

The regulator setting to achieve the given light- and full-load distribution curves is determined by the intersection, *A*, of the projections of the two voltage curves for the feeder. Thus the voltage-regulating relay must be set to 120 volts and, since the compensator responds only to the current in the feeder, its impedance must be adjusted to a fictitious length equal to that from the regulator to the intersection *A*. With the regulator at full "buck" the substation bus voltage at light loads can be as high as 137 volts and at full "boost" at full load as low as 121 volts. It should be noted that the design requirements, as based on paragraph 6.002 of the 1942 American Standards Association Transformer Standard *C*-57, are 132 volts or 110 per cent of rated voltage of the regulator at no load, and 126 volts or 105 per cent of rated regulator voltage at full load.

With the foregoing assumptions, the minimum voltage at a customer's service entrance occurs under full load at the last customer in the secondary of the last transformer (speaking electrically) on the last lateral. This point is indicated by y and equals 114 volts. The maximum voltage occurs at the first customer on the secondary of the first transformer when this particular transformer is lightly loaded but the system as a whole is at full load. This point is indicated by x and equals 124 volts for this system. The total service voltage spread is ten volts. At any one customer the spread is not this great. The occurrence of light loads on the first transformer with full loads on the remainder of the distribution circuit involves some element of probability, but nevertheless it is generally agreed it must be provided for. The voltages at light load fall within the values discussed and therefore do not constitute a limitation.

Figure 1c depicts the effect of the voltage-regulating-relay band width and errors in the control device upon the performance of the system. The shaded portion applies to a voltage-regulating relay set in the same manner as for Figure 1a except that the relay band width is ±1 volt (0.8 per cent). Because of lack of control within this band the voltage at any location can fall anywhere within the band so marked. At full load the minimum service voltage—occurring again at the last customer connected to the last transformer—is y_1 instead of y, a value one volt less. If in attempting to regulate for this voltage the substation bus is 121 volts (as assumed in the first case) the regulator does not have to take its full "boost" position. Using the full capability of the regulator the substation bus can drop to E_4 (120 volts) without dropping the minimum service voltage below y_2.

To determine the maximum voltage that might be obtained at a customer's service entrance, consideration must be given to the upper border of the band of regulation, which gives rise to the value x_1 (125 volts). Here, however, more definite consideration must be given to the manner in which the substation-bus voltage varies. If it is assumed that at full load on the feeder the substation-bus voltage always lies between E and E_1 then even if the regulator is attempting to regulate for a value of x_1 at the

first customer of the first transformer, this value of x_1 is unattainable because even with full "boost" the value of x cannot be exceeded. On the other hand, if the assumption is made that for full load on the feeder the substation bus voltage might have any value near E but not below it, then the bus voltage might have the value E_1 while the regulator is attempting to regulate on the upper border of range and therefore the maximum voltage on a customer's service is x_1. A similar condition applies for larger values of substation voltage for full load in the feeder except that the regulator need not use full "boost" positions. The light-load voltages fall within the limits mentioned. Therefore, it may be concluded that for the conditions assumed a $\pm$ one-volt relay band width decreases the minimum voltage at customer's service entrance by one volt and increases the maximum voltage between zero and one volt depending upon the assumptions made with regard to the substation-bus voltage.

Distribution system design must allow for a reasonable voltage-regulating-relay band width and the shaded portion of Figure 1c shows a representative condition with a service voltage spread of 12 volts (125 volts at x_1 to 113 volts at y_2). This 12-volt service-voltage spread corresponds to the preferred utilization-voltage spread (with three volts drop in interior wiring) of Edison Electric Institute publication No. J8, "Utilization Voltage Standardization Recommendations," and with the voltage profile shown as Figure 6 in the EEI report.

Figure 1c also shows the voltage distribution along a distribution circuit when, in addition to the $\pm$ one-volt relay band width the voltage-control relay has an additional error of $\pm$2.5 volts, making a total error of $\pm$3.5 volts or say, $\pm$ three per cent. Under this condition, the minimum voltage at the customer's service y_4, is reduced by 3.5 volts to 110.5 volts, and the maximum customer voltage, which occurs again at the first customer of the first transformer while the remainder of the system is fully loaded, is x_3, and equals 127.5 volts. Again this maximum voltage is based upon the assumption that the substation voltage might have any voltage in the neighborhood of E but not below it. If the full-load voltage of the substation bus equals E, the maximum customer's service voltage is x. Thus, the minimum voltage is 110.5 and the maximum voltage lies between 125 and 127.5 volts.

With the control relay and compensator adjusted for the settings indicated in Figure 1b, the full-load condition sets both the maximum and minimum voltages at the service entrances. The light-load values fall within these limits. There exists, therefore, some tolerance for which light-load values can be set. In Figure 2b an alternate adjustment is indicated for which the voltage at the feed point is fixed at 125 volts at both light and full load. This adjustment is accomplished by setting the relay for 125 volts and the compensator for a drop corresponding to that of the feeder impedance to the feed point. With this setting the maximum voltage at the service entrance at light loads equals x. The advantage of this setting over that of Figure 1b is that it permits a greater variation in the substation-bus voltage at the expense, however, of greater variation of the voltage of individual customers. With the setting of Figure 2b the variation of voltage between light load and full load would be more noticeable to certain customers. The effect of errors in the control devices would be substantially the same.

Generalizing upon the effect of control errors, it may be seen that a $\pm n$-volt error may reduce the minimum voltage at customer's service entrance by n volts and increase the maximum customer voltage between zero and n volts depending upon the manner in which the substation bus voltage varies. The total variation of customer voltage may thus be increased between zero and $2n$ volts. If, however, the recommended service-voltage spread indicated by the shaded area of Figure 1c is not to be exceeded, the voltage at the first customer must not be greater than 125 volts and the voltage at the last customer's entrance must not be less than 113 volts. To maintain these voltages, the design voltage spread of ten volts, as indicated in Figure 1b, must be reduced by five volts ($\pm$2.5 volts), or in other words, the impedance of the distribution circuit beyond the "feed point" must be halved to provide adequate voltage to all customers. This may require doubling the distribution facilities beyond this point. The error increases the maximum range over which the bus voltage may vary and in this regard does not limit the availability of the full kilovolt-ampere capacity of the regulator.

IMPORTANCE OF ERRORS

The error of $\pm$3.5 volts used in preparing Figure 1 constitutes an assumed cumulative error of $\pm$3.5 volts and represents some present-day regulators on the basis that all the errors may occur simultaneously and be in the same direction. The errors vary slowly with temperature, load, and frequency. Their coincidence and frequency of occurrence is a function of the law of probability.

It is evident that with an assumed cumulative error of $\pm$2.5 volts in the control equipment, and with a relay band width of $\pm$ one volt, which is a minimum practical value, some seven volts or about six per cent of the total regulating range is unusable. The regulator may therefore be only about 70 per cent effective. This assumes that all the errors are cumulative, occur at the same time, are of the same magnitude at light load as at full load, and that the errors operate to limit the buck as well as boost operation of the regulator. If the guaranteed performance of the regulating equipment is based on the cumulative occurrences of these errors, the user has no

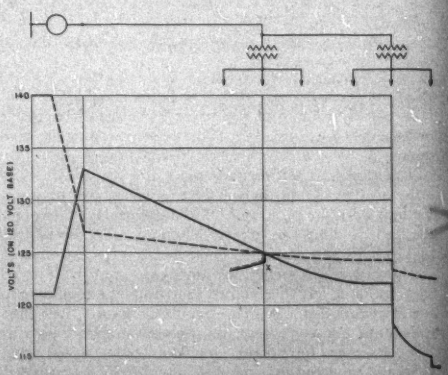


Figure 2. Voltage along distribution circuit with voltage at feed point equal to 125 volts at both light-load and full-load condition

choice but to base distribution-circuit design upon this guarantee.

To maintain the same limits of customer voltage with an error in the control device as without error requires liberalizing of the distribution system either through over-installation of transformers or through reduction of the impedance of the primary mains and laterals. Some idea of the probable cost of additional system strengthening which may be required can be obtained from an analysis of the investment in transformer-secondary combinations on residential circuits designed for different voltage-drop limits. The increased cost of these transformer-secondary combinations designed for one volt less drop is in the order of two dollars or more per kilovolt-ampere of diversified circuit demand for 4,160-volt circuits, and in the order of three dollars or more per kilovolt-ampere for 7,200-volt circuits. The value of adequate regulation may be even better appreciated if it is realized that ordinarily there are about ten volts to "spend" in the design of distribution circuits and each volt lost due to inadequate regulator performance represents one volt out of ten (rather than one volt out of 120 volts) in the measurement of increased investment required. It may be possible to design and build regulators having better performance characteristics without too great an increase in cost. If so, an over-all improvement in the economics of distribution may reasonably be effected by investing more money in regulators of improved performance characteristics, thereby affording a greater saving in the distribution circuit itself.

The accuracy requirement for voltage-regulator control depends upon the length of the circuit as well as upon the range of satisfactory voltage to the user. If the regulator is located at or close to the load less accurate control is required for the same range of utilization voltage than if the loads are distributed over the length of a long line having considerable voltage drop.

ACCURACY OF REGULATOR PERFORMANCE

The various factors involved when considering the over-all accuracy of feeder-voltage regulators should be divided into two general classifications. These are: first, errors incident to the design and manufacture for which limiting values may be established and compliance therewith verified by a factory test; second, other factors which may be affected by the application or by adjustment, or which may not be subject to verification by a factory test.

FACTORS INCIDENT TO THE DESIGN AND MANUFACTURE

These include the following:

1. *Ratio errors in the potential transformer or potential supply winding.* These should include (*a*) the ratio error with no load in the regulator, and (*b*) the effect of the load current and regulator position on the ratio error. The only burden on the potential transformer or potential supply is the voltage-regulating relay. Regardless of the magnitude of the load on the regulator this burden introduces an error that is essentially constant and can be compensated by the balance adjustment of the voltage-regulating relay. An indicating instrument connected across the voltage-regulating relay may not be a true measure of the voltage across the primary of the regulator.

2. *Errors in the voltage-regulating relay and the associated control circuits.* It is understood that some present designs have been influenced by a desire to keep the control equipment losses to an absolute minimum. Perhaps this consideration has been unduly emphasized.

3. *Ratio errors in current transformers used to energize line-drop compensators.* Limiting values of these errors should be based upon loading the current transformer with an impedance that ranges from zero to such a value that will introduce into the supply for the regulating relay a voltage equal, at rated regulator current and expressed as a percentage of that supplied by the potential winding at rated voltage, to the maximum boost percentage of the regulator. The current through the secondary of the current transformer should vary from a value corresponding to 0 to 100 per cent of the rated value of the series winding of the regulator. It is customary, however, to supply a 24-volt (20 per cent) compensator. The value of 24 volts was fixed upon so that the same control system could be used on either a ±10-per-cent or ± 20-per-cent regulator. Actually in the extreme application the compensator should be good for the entire range (20 per cent on a ± 10-per-cent regulator) but the more usual operating point is closer to the maximum-raise range. The use of a 24-volt compensator provides for the extreme case for a ± 10-per-cent regulator and the more usual case for a ± 20-per-cent regulator.

It has been suggested that the limiting regulator error based upon the foregoing factors should not be exceeded over a frequency range of ±0.5 per cent (±0.3 cycle on a 60-cycle system) and over a range of external ambient temperature from −30 to +40 degrees centigrade. The voltage-regulating relay and other equipment will usually be mounted inside some type of container or housing and will, therefore, operate at a temperature in excess of the maximum ambient temperature of 40 degrees centigrade. Since the temperature inside the container, or housing, will vary with the temperature design of the housing, it is better to specify that the relay must meet its performance specification in an ambient temperature of 40 degrees centigrade outside the regulator housing than on the basis of specifying a fixed maximum temperature within the enclosure.

In considering the effects of temperature, the variations of the temperature of the conductor, whose impedance determines the regulator setting should likewise be borne in mind. Between light load on a very cold day and full load on a very hot day the resistance of the line might change as much as ±20 per cent from a mean value. This may result in a variance of regulated voltages of as much as ±1.0 per cent when using a compensator whose resistor is constant over the entire temperature range. So-called temperature errors in the compensator usually reduce the magnitude of this variance. The amount of compensator error is affected by whether the regulator is located indoors or outdoors. Since present thought is centered about errors of about 1.0 per cent, the variance due to conductor temperature may equal or exceed the total error of the control system.

OTHER FACTORS

These include the following:

1. *Line-drop compensator taps.* It has been difficult to design a tapped reactor, such as may be used for the reactance element of the compensator, to obtain a definite amount of reactance on all taps without some error. Errors of this style are constant and can be compensated to some extent by the operator when the compensator is adjusted. Since the load distribution on a distribution circuit is continually changing, checking the performance of the reactance element of the line-drop compensator with field voltmeter readings at any single location is extremely cumbersome and difficult. The regulator performance is best measured by determining the voltage conditions at the point of first and last customer

for the maximum and minimum load conditions. Graphic voltmeter charts are not always sufficiently accurate to check regulator control settings.

2. *Relay band width.* It is recognized that there is a minimum practical band width which can be obtained within economic limitation of design. However, the operator may adjust the relay to obtain any value of band width from the designed minimum value up to the designed maximum value.

3. *Change in calibration of the voltage-regulating relay over a specified period of time or the so-called "drift."* Change in calibration may be caused by mechanical wear due to dust, moisture, friction, and an undue amount of rough handling of the movable parts of the relay. This is a factor which cannot be checked or demonstrated by any reasonable factory test. Limiting specifications should not be incurred where it is impossible to demonstrate that a device can or cannot meet the specifications. Furthermore, since the "drift" of a voltage-regulating relay is affected by the wear and tear on the device in actual use, any specification covering this item is fundamentally a specification covering the life of the device. Regardless of the guarantee given on a piece of apparatus by the individual manufacturers, there is an implied guarantee that the apparatus will have a reasonable life and that the design of the individual component parts of the piece of apparatus will be such that it will have a performance consistent with the other parts of the apparatus.

CONCLUSION

It is hoped that the foregoing discussion will clarify thought with regard to the nature and the effect of errors in the control system of feeder regulators. The transformer subcommittee at present is continuing the task of preparing a standard for the specification of accuracy tolerance and for the establishment of accuracy classifications. Provision will be made so that as improvements materialize the best accuracy consistent with cost can be incorporated.

It is suggested that distribution and transmission engineers, equipment application engineers, and others interested in system design and layout consider this matter as applied to their own systems. Comments relating to this subject should be directed to the chairman of the transformer subcommittee.

A Physical Conception of Single-Phase Motor Operation

ROBIN BEACH
FELLOW AIEE

Textbooks and other treatises that purport to explain the physical concepts of the operation of the single-phase induction motor by the cross-field theory do so mostly by employing simultaneously developed space-phase and vector diagrams. Unfortunately this method has not been found adequate nor of proper approach to provide an understanding of the physical reactions within the motor. The author has evolved a technique for presenting the basic concept of how the motor develops its torque and power by which he constructs, concurrently with the development of the space-phase diagram, the rotor voltage, current, and flux curves of the correlative time-phase diagram.

IN the development of the cross-field theory for the single-phase induction motor, a particularly favorable opportunity is provided to present a clear interpretation of how the stator and rotor fluxes and currents mutually interact to develop torque and maintain rotation. The mathematical relationships are presented in various textbooks and papers on the subject, but for the first study of the subject the mathematical treatise should be given secondary importance to that of conveying a clear understanding of the physical reactions of the electric and magnetic quantities within the motor.

In addition, a clear and logical treatment of the physical behavior of this motor affords a unique opportunity, coming as this subject does near the end of the course in a-c machines, to provide a comprehensive review of almost all the basic relationships applying to electrical machines. Such a critical retrospection of these principles serves admirably to re-emphasize, and to reorganize into more applicable form, the important fundamentals which are basic to both those static and rotating types of machines previously studied.

The types of systems employed to provide starting torque for single-phase induction motors and which modify the physical structures of the stator and rotor of this motor, as compared with the polyphase induction motor, will not be given consideration in this treatise, as that phase of the subject is irrelevant to this paper and the subject is treated adequately elsewhere.

Robin Beach is professor and head of the electrical-engineering department, Polytechnic Institute of Brooklyn, and consulting engineer, Brooklyn, N. Y.

BASIC PHYSICAL CONCEPTS

As shown by the cross-sectional view in Figure 1, the stator winding is so arranged that, when it is energized from the supply line, the magnetic field which it produces alternates cyclically along the vertical Y axis. Let us assume that the turns of the winding are so disposed in the slots of the stator core as to produce a sinusoidal space distribution of flux circumferentially around the air gap

under the polar areas, and that with respect to time the flux also varies sinusoidally. Of the total magnetic field, a small part of it only—the leakage flux—encircles locally the stator inductors without crossing the air gap into the domain of the rotor. This leakage flux is considered to give rise to the leakage reactance voltage in the primary winding. The remainder of the magnetic field—the mutual flux ϕ_M—interlinks the rotor, as well as the stator, inductors.

In Figure 1, the motor is shown to contain the customary squirrel-cage rotor bars. These inductors on one side of the vertical plane which contains the rotor axis, the trace of which is Y–Y, could be considered paired at any instant with those on the other side of the vertical plane. This concept is shown in the simple conventional diagram of Figure 2.

The periodic variation of the mutual flux ϕ_M of the main field induces a transformer voltage both in the stator winding and in the rotor winding. In the stator winding, the vector difference of this transformer voltage and the impressed line voltage is the leakage impedance voltage, and it is proportional to the primary current. Its variation between no load and full load causes a small change in the magnitude of the mutual flux ϕ_M. But for the purpose of this qualitative presentation, the main field flux ϕ_M may be considered constant.

TRANSFORMER VOLTAGE INDUCED IN ROTOR BY MAIN FIELD

In the rotor winding, the transformer voltage, which is induced there by the alternations of the main field ϕ_M, is only one of several component voltages which are to be individually considered during the development of the cross-field theory. The amplitude of this induced voltage is determined by the magnitude of the mutual flux of the main field, by the frequency at which the flux alternates, and by the equivalent number of turns in the rotor winding. In time phase, the voltage is in lagging quadrature with the flux ϕ_M. This voltage causes currents in the closed rotor circuits, as shown by the paired inductors of Figure 2, for each of which the magnetic axis is perpendicular to the plane containing the paired inductors, and, in consequence, it is coincident in each case with the magnetic axis of the stator winding, the Y axis. And further, the induction of this transformer voltage is not influenced or modified by whether the rotor is stationary or in rotation.

When the rotor is in rotation, the successive inductors, as can be reasoned from the geometry of the squirrel-cage winding and shown in Figure 2, momentarily form new pairs as they pass through the vertical plane, the trace of which is the Y axis. On the basis of this hypothesis of how the rotor inductors, when in rotation, may be considered to form themselves continually into pairs distributed about the Y axis, the resulting magnetic axis for these pairs is maintained coincident at all times with the magnetic Y axis of the primary winding.

The transformer voltage induced in the rotor may be designated by appropriate subscripts to indicate that it results from transformer action, T; from the main field mutual flux, ϕ_M; and that it causes, through the current it produces in these paired rotor turns, a resultant magnetomotive force along the Y axis—the magnetic axis of the stator field. This voltage, E_{TMY}, then may be identified fully from the appended subscripts.

The magnetic effect along the Y axis produced from these paired rotor inductors carrying the rotor current I_Y, which results from E_{TMY}, is counterbalanced in the stator winding by an equal number of ampere-turns, and so if the equivalent number of turns in the rotor and in the stator are equal, then the rotor current has its exact counterpart in the primary. For the sake of simplicity let us assume unit transformation ratio throughout this presentation. These voltage, current, and magnetic effects

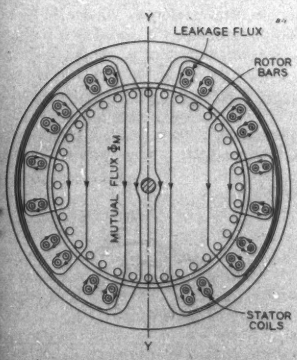


Figure 1. The energized stator windings cause leakage fluxes about the stator conductors, mutual flux in the rotor, and induced voltages and currents in the rotor inductors. No torque is developed at standstill

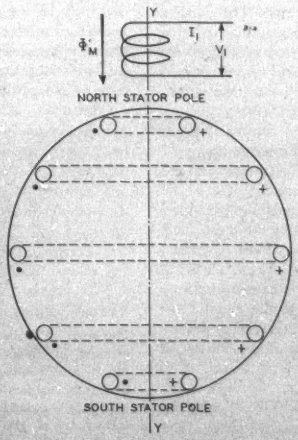


Figure 2. The assumed pairing of squirrel-cage rotor bars about the Y axis helps to visualize the magnetic reaction of the rotor with the stator by transformer effect

The voltage induction in the rotor bars is shown in the direction indicated by the dots and crosses for an increasing stator field

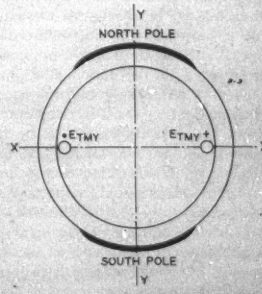


Figure 3. A hypothetical equivalent coil replaces in effect the paired rotor inductors centered about the coaxial magnetic Y axis

This concept is utilized to aid the visualization of the magnetic effects of the rotor windings and of the directions of induced voltages, currents, and fluxes

in the motor, even when rotating, are precisely identical to those which occur in a transformer when its secondary winding is short-circuited. In order for the current in the rotor inductors to modify the stator current, as under a change in load, for instance, it must have its magnetic reaction along the Y axis, as Figure 2 shows it has, and thus magnetically interlink the stator winding. The greater the rotor current is, the greater the stator current must be in order to counterbalance it magnetically.

The direction of the induced voltage E_{TMT} and the direction of the dependent magnetic effect of its current through the resulting magnetomotive force are more simply represented by considering all of the paired inductors in Figure 2 to be replaced, for the particular instant being considered, by a coil of an equivalent number of turns and located in the horizontal plane through the rotor axis, so as to retain the same magnetic Y axis, as shown in Figure 3. This hypothetical equivalent coil of Figure 3 is properly labeled to show the identity of the voltage induced in it, and by means of the conventional dot or cross for the respective head or tail of an arrow, the direction of the induced voltage for a particular instant is indicated on the figure. The dots and crosses showing the instantaneous directions of all voltages in figures throughout this paper are placed outside of, but closely adjacent to, their respective inductors and then labeled with their identifying voltages.

In the development of the following presentation, one particular instant of time is assumed, although it will be observed later that the same terminal results obtain by the use of any other chosen instant. The instant of time to be considered is shown by the vertical line on the time-phase diagram, Figure 4, which is marked instant 1 at the bottom of the graph. At this instant the curve representing the stator main field, which is labeled ϕ_M (1), is increasing in magnitude, and the assumption is made that the upper stator pole in Figure 3 is of north polarity. The polar areas on the stator, as so produced by the impressed main field, are also shown in Figure 3, for clarity and emphasis, by the heavy circular arcs. The voltage E_{TMT} is shown on the time-phase diagram, Figure 4, as curve (2), having been drawn in quadrature lagging phase with respect to the stator field ϕ_M which induces it. Numbers in parentheses indicate the order of derivation, and coincidentally assist in reference.

With the polarity of the stator field assumed, as in Figure 3, and with ϕ_M increasing, as shown at instant 1 of Figure 4, the direction of the induced rotor voltage E_{TMT} is then determined by the application of Lenz's law. Its direction is such that its resulting magnetic effect along the Y axis opposes the *increase* of the stator field ϕ_M, and this direction is so indicated on the space-phase diagram, Figure 3, where the voltage is properly labeled with the dot and cross, as shown.

Thus, by the gradual development of the time-phase diagram, curve by curve, correlatively with that of the space-phase diagram, the interpretation of the theory of the motor is revealed step by step.

SPEED VOLTAGE GENERATED IN ROTOR BY MAIN FIELD

When the rotor inductors rotate through the main field ϕ_M, speed voltages are generated in one direction in all of those inductors which are, at the instant, above the horizontal plane, and voltages in the opposite direction are

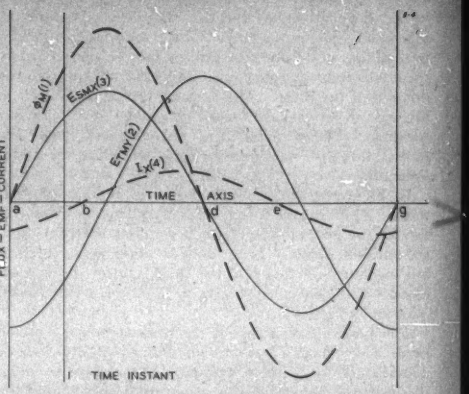


Figure 4. The time-phase diagram showing the rotor voltages and current which result from the transformer and speed action by the main stator field

produced in the inductors occupying positions below the horizontal plane. These inductors, in which voltages are generated by their speed action through the main field, may also be regarded as paired, except that, in so doing, one above and a corresponding one below the X axis are considered to lie in a vertical plane, each pair with its magnetic axis individually coincident with the X axis, as shown in Figure 5.

This speed voltage E_{SMX} is identified by appending the subscripts S to imply speed action in its generation, M to indicate generation in the main field, and X for the X axis along which the coils exert their magnetomotive force. The voltage E_{SMX} is generated by, and is in time-phase with, the main field flux ϕ_M, and on the time-phase diagram, Figure 4, this voltage is so drawn, as curve (3). If the motor is assumed to be operating under load, it then has an appreciable slip, and hence the speed voltage E_{SMX} is less in magnitude than the transformer voltage E_{TMT} of curve (2) by the proportion that the speed is less than synchronous. The transformer voltage is, of course, independent of speed. Should the motor be run at synchronous speed, by driving it, the speed voltage E_{SMX} would then be equal to the induced voltage E_{TMT}.

The currents in the paired inductors, which result from the speed voltages, produce their magnetomotive forces,

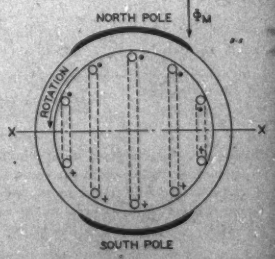


Figure 5. The direction is shown for the speed voltage E_{SMX} as generated in the paired inductors of the squirrel-cage winding under the given conditions of polarity and direction of rotation

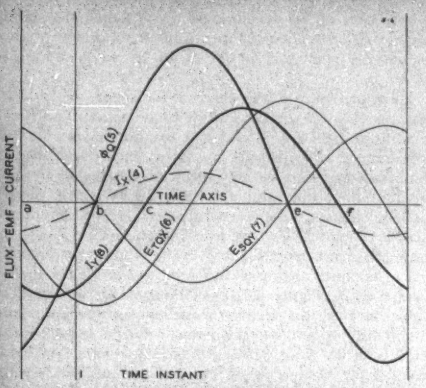


Figure 6. The time-phase diagram showing the rotor voltages and currents which result from the transformer and speed action by the quadrature field

and, hence, their resultant field, ϕ_Q, along the X axis, and accordingly this field lies in exact space quadrature at all times with the main field ϕ_M. By reason of this quadrature field, the name "cross-field" theory is derived. Because these paired inductors possess the traits of an iron-core reactor, with no other winding upon which their resultant flux can react and thereby lower their impedance, this exciting current I_X of the rotor, that results from the speed voltage, lags E_{SMX} in time phase by nearly 90 electrical degrees. In magnitude this exciting current I_X, which causes the quadrature field ϕ_Q and which for linear magnetization is about proportional to the rotor speed, is slightly less than the exciting current for the stator field—a quantity which is assumed in this presentation to be independent of speed and hence, to be constant. This stator exciting current is not included on Figure 4, but the rotor exciting, or quadrature field, current I_X is shown as curve (4), and it is drawn to lag E_{SMX} which causes it by a large phase angle, as may be observed from the time-phase diagram.

In the interests of simplicity, the quadrature field ϕ_Q is considered here as being proportional to and in time-phase with the rotor exciting current I_X rather than being in phase with the magnetizing component of the exciting current, a current which lags I_X by a small angle and which lags E_{SMX} by 90 electrical degrees. The quadrature field ϕ_Q is so drawn in phase with the exciting current I_X—the latter having been redrawn for orientation—in Figure 6 wherein the field flux is shown as curve (5). Also at a particular instant, the quadrature flux ϕ_Q may be regarded as being caused by the magnetomotive force of the field current I_X in an equivalent hypothetical coil which replaces in effect the magnetomotive forces of all the paired inductors on the rotor, as shown in Figure 5, and which have their magnetic axes coincident with the X axis. This equivalent hypothetical coil is shown in Figure 7, and for the instant 1 when the upper main pole is of north polarity, and for a counterclockwise direction of rotation, the direction of the generated speed voltage E_{SMX} in this coil is also shown.

POLARITY OF THE QUADRATURE FIELD

Before being able to proceed with the development of the theory, the polarity of the quadrature field at instant 1 must be determined. Since the direction at a particular instant of the exciting current I_X in the rotor windings determines the direction of the quadrature field, this essential information is obtained by reference to the time-phase diagram of Figure 4. Because of the large phase angle of the rotor cross-field current I_X behind the speed voltage E_{SMX} which causes it, its polarity at instant 1 is seen from Figure 4 to be oppositely directed to E_{SMX}. Thus, in Figure 7, the exciting current I_X is shown inward for the inductors at the top of the equivalent coil and outward at the bottom—the dots and crosses, representing current, being placed within the inductors.

A current in this direction in the rotor bars causes its field—the quadrature field ϕ_Q—to form a north polar surface in the stator at the right and a south polar surface at the left. The polar areas formed at the surface of the stator core both for the main and quadrature fields are indicated by the heavy circular arcs in Figure 7. The quadrature poles thus formed by the magnetomotive force of the exciting current I_X within the rotor bars are represented by the heavy dashed lines as a means of differentiating them from the main poles which are produced by the magnetomotive force of the stator winding. Since the quadrature field comes into being as the result of the speed voltage E_{SMX} and its dependent current I_X, it is not present when the rotor is at standstill—and hence the dashed-line construction to represent its polar areas.

TRANSFORMER VOLTAGE INDUCED IN ROTOR BY QUADRATURE FIELD

An inspection of Figure 6 shows the curve of the quadrature field ϕ_Q (5) to be decreasing toward zero at instant 1, and, because of this, transformer voltages are being induced in the same group of rotor inductors in which speed voltages from the main field ϕ_M are being generated, that is, in those inductors coaxially paired about the X axis, as shown in Figure 5. By the application of Lenz's law again, the induction is found to be in such a direction as to tend to sustain the decreasing quadrature field, and thus these induced voltages are seen to be oppositely directed to those generated by speed action from the main field. The voltages are inward for the inductors above the X axis and outward below.

The polarity of the voltage induction is shown in Figure 7 by the dot and cross associated with the voltage E_{TQX}. Here the subscripts have the following designation: T signifying transformer action in the coils by virtue of the variation of the cross field ϕ_Q, and X indicating the X axis along which is directed the resultant magnetic action of the rotor coils that are coaxially disposed about the X axis. Only currents are shown in their momentary directions by appropriate dots and crosses placed within the conductors, while all voltages have their directions indicated by dots and crosses placed outside of, but near, the conductors, and properly labeled with their associated voltages.

The transformer voltage E_{TQX} which is induced by the quadrature field ϕ_Q lags the flux by 90 electrical degrees. The magnitude of E_{TQX} is almost equal to that of the speed voltage E_{SMX}, being less only by the vector difference of the rotor leakage impedance voltage which results

from the small rotor current I_X. On the time-phase diagram, Figure 6, this transformer voltage E_{TQX} is drawn as curve (6), in lagging quadrature with the flux ϕ_Q, and in magnitude a little less than that of E_{SMX}. Because these two voltage curves are not quite in phase opposition, the value of E_{TQX} at instant 1 is slightly greater than the value of E_{SMX}, a fact which accounts for the rotor exciting current I_X being momentarily in the direction opposite to E_{SMX}, as previously described and as shown in Figure 7.

SPEED VOLTAGE GENERATED IN ROTOR BY QUADRATURE FIELD

With the polarity of the quadrature poles corresponding to the conditions of instant 1, as shown in Figure 8, and for counterclockwise direction of rotation, speed voltages are generated in those inductors which are under the influence of the quadrature poles and which inductors are considered as being paired coaxially about the Y axis. These are the same paired inductors which are shown in Figure 2 as having induced in them the transformer voltage E_{TMY} from the main field ϕ_M. The direction of the speed voltage E_{SQY} is found to be outward in the inductors to the right of the Y axis under the north pole and inward for those at the left under the south pole—directions which are observed to be opposite to those for the transformer voltage E_{TMY}.

In placing the curve for the speed voltage E_{SQY} on the time-phase diagram, Figure 6, it is to be drawn either in time phase with the quadrature field ϕ_Q from which it is generated or in time-phase opposition to it, in which latter case the speed voltage would appear as a counter-voltage in the rotor. The information for determining in which of these two positions with respect to the quadrature field the speed voltage E_{SQY} is to be drawn appears from the fact already established, namely that the direction of the speed voltage E_{SQY} is opposite to that of the transformer voltage E_{TMY}. Reference to the time-phase diagram, Figure 4, shows the direction of the transformer voltage E_{TMY} (2) at instant 1 to be the same as the quadrature field ϕ_Q (5), Figure 6, that is, both are negatively directed. So, therefore, the speed voltage E_{SQY}, being of opposite direction to E_{TMY}, as shown by Figure 8, is drawn in time-phase opposition to the quadrature field ϕ_Q which causes it. Before the speed voltage E_{SQY} can be drawn as a curve on Figure 6, its maximum value must be determined.

Since the transformer voltage E_{TMY} and the speed voltage E_{SQY} appear as oppositely directed voltage components in the same group of rotor inductors, Figure 8, their vector difference is then the unbalanced leakage impedance voltage drop which causes the load current I_Y in those inductors coaxially grouped about the Y axis. The transformer voltage E_{TMY}, being induced by the assumed constant main field ϕ_M, is independent of speed, and, hence, it is the largest voltage component in the rotor. The speed voltage E_{SQY} is the smallest.

This speed voltage E_{SQY} is smallest because it is dependent upon the magnitude of the quadrature field, which is less than that of the main field by the approximate value of the rotor speed compared with that of the synchronous speed, and also it is dependent upon the speed of cutting the quadrature field which is likewise less than the synchronous speed. In other words, the speed voltage E_{SQY} is about proportional to the square of the rotor speed. To illustrate this numerically, assume the rotor speed is 90 per cent of the synchronous speed, then the speed voltage E_{SQY} is about 81 per cent of the value of the transformer voltage E_{TMY}, or about 19 per cent less in value.

Thus, in Figure 6, the curve of the speed voltage appears as E_{SQY} (7), drawn in time-phase opposition to the quadrature field ϕ_Q (5) and to a magnitude less, by the approximate ratio of rotor speed to synchronous speed, than E_{TQX} and considerably less than E_{TMY}—less by the square of the above ratio of speeds. Because of the phase difference between the speed voltage E_{SQY} and the transformer voltage E_{TMY}, the transformer voltage E_{TMY} at instant 1 is seen from Figure 4 to be of large magnitude and of opposite direction compared to that of the speed voltage E_{SQY}, Figure 6. The difference in voltage between them is the leakage impedance voltage at this instant and it is obviously large. As the leakage impedance of the rotor winding is the same along any axis of the rotor because of its electric and magnetic symmetry, this large leakage impedance voltage results from a large load current I_Y in the rotor, as the impedance itself is relatively small.

THE LOAD CURRENT I_Y OF THE ROTOR

The load current I_Y in those equivalent rotor inductors, as shown in the hypothetical coil of Figure 8, is caused by the transformer voltage E_{TMY}, and the magnitude of the current is so controlled by the countervoltage E_{SQY} as to accommodate itself to variations in the load. As the load on the motor increases, the speed decreases and with it the speed voltage E_{SQY} decreases. Thus with decreasing speed the vector voltage difference between the constant voltage E_{TMY} and the variable speed voltage E_{SQY} increases, and in proportion to it, the load current I_Y increases and simultaneously improves its power factor with respect to E_{TMY}. This load current I_Y is shown in suitable magnitude and phase in Figure 6 as curve (8). It lags E_{TMY} by a small angle for heavy load and by a large angle for light load.

In the final analysis, the correct magnitude and phase of I_Y, as well as of some of the other quantities, can be determined only by the simultaneous solution of three basic equations which contain and interrelate the stator input current I_1, the rotor exciting current I_X, and the rotor power current I_Y. This information expressing the exact quantitative values is not necessary to this qualitative explanation of the physical operation of the motor. Further details may be found in references 1 and 2.

DEVELOPMENT OF MOTOR AND GENERATOR TORQUES

The complete space-phase diagram for instant 1 and for the assumed direction of rotation consists of the superposition of Figure 7 and Figure 8. This composite diagram is represented by Figure 9 except that, in the interests of clarity, all voltages and their directions are omitted, as they were only incidental to determining the directions of the currents I_X and I_Y and of the quadrature field ϕ_Q—all at instant 1. The dots and crosses within the conductors indicate here, as in all previous diagrams, the directions of the currents.

An inspection of Figure 9 divulges the essential information that (1) the quadrature field current I_X exists in those inductors which lie under the main poles, and

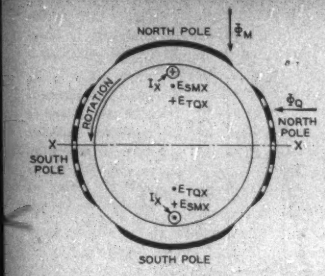


Figure 7. A hypothetical coil equivalent to the squirrel-cage winding in magnetic effect along the *X* axis, showing at instant 1 of the time-phase diagram the directions of the speed voltage E_{SMX}, the exciting current I_X, the quadrature field ϕ_Q, and the transformer voltage E_{TQX}

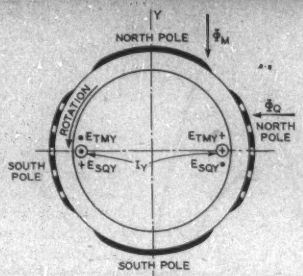


Figure 8. A hypothetical coil equivalent to the squirrel-cage winding in magnetic effect along the *Y* axis, showing the directions of the transformer voltage E_{TMY}, the speed voltage E_{SQY}, and the load current I_Y, all at instant 1 of the time-phase diagram

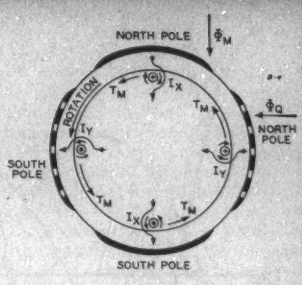


Figure 9. The composite space-phase diagram showing the directions of the rotor currents, fluxes, and resulting torques in the equivalent rotor coils for instant 1 of the time-phase diagram

(2) the load current I_Y is in those inductors which lie under the quadrature poles. This is true at all times, and hence these current-carrying inductors for currents I_X and I_Y develop torque with their respective main and quadrature fields. The directions and the relative magnitudes of the torque for both assumed groupings of inductors, at instant 1, are shown by the arrows labeled T_M. If the developed torque is exerted in the direction of the rotation, it is motor torque, otherwise it is generator torque. Its magnitude depends upon both the strength of the field and the value of the current at a given instant, and hence upon their product, as $\phi_M \times I_X$ and $\phi_Q \times I_Y$.

THE AVERAGE MOTOR TORQUE

Since both of these current-flux reactions are seen from Figure 9 to develop motor torque at instant 1, they may both be plotted on a time-phase diagram either upward or downward, as desired. In order to provide ultimately a time-phase diagram of the torque curves, free from the distracting complication of unessential curves, each flux curve with its torque-producing current curve have been reproduced from Figure 4 and Figure 6 onto Figure 10. The motor torque was arbitrarily assumed in the upward direction—above the time axis. At instant 1 the magnitudes of both the quadrature field ϕ_Q and the load current I_Y are seen to be of considerable proportions with respect to their maxima, and thus the motor torque which is proportional to their product $\phi_Q \times I_Y$ is of considerable magnitude. For other instants of time from instant 1 toward the origin at instant *a*, the magnitude of the quadrature field ϕ_Q increases more than two-fold, while that of the load current I_Y changes very little, and hence the motor torque $\phi_Q \times I_Y$, instant by instant, increases to its maximum value, as shown to be attained at about instant *a*. From this maximum, for successive instants of time to instant *b*, the value of torque—$\phi_Q \times I_Y$ (9) decreases to zero, at which instant the quadrature field ϕ_Q is zero.

As the quadrature field ϕ_Q reverses its polarity, the conductors under these reversed poles, which are still carrying the load current I_Y (8) in the same direction as before, now develop reversed torque, that is, generator torque. This is drawn as such in the reversed direction, and it is so shown on Figure 10, from instant *b* to instant *c*. At instant *c* the load current I_Y becomes zero and, in consequence, the generator torque $\phi_Q \times I_Y$ reduces to zero. Between the time interval *c* to *e* the current I_Y is in a direction reversed to that existing from instant *a* to instant *c*, thus reversing the direction of the torque $\phi_Q \times I_Y$, and hence changing it from generator, back again, to motor torque. At instant *e*, the field ϕ_Q reverses and, hence, the torque is reversed so that generator torque is developed thereafter from instant *e* to instant *f*. At instant *f* the current I_Y reverses, and thus the torque is again reversed, motor torque being developed from instant *f* to instant *g*—thus completing the cycle.

The torque $\phi_Q \times I_Y$ is seen to be predominantly motor

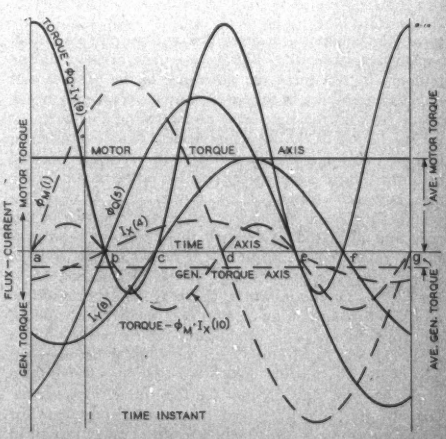


Figure 10. The time-phase diagram showing the development of motor and generator torques resulting from the quadrature field and power currents in the rotor reacting with the stator and quadrature fields, respectively

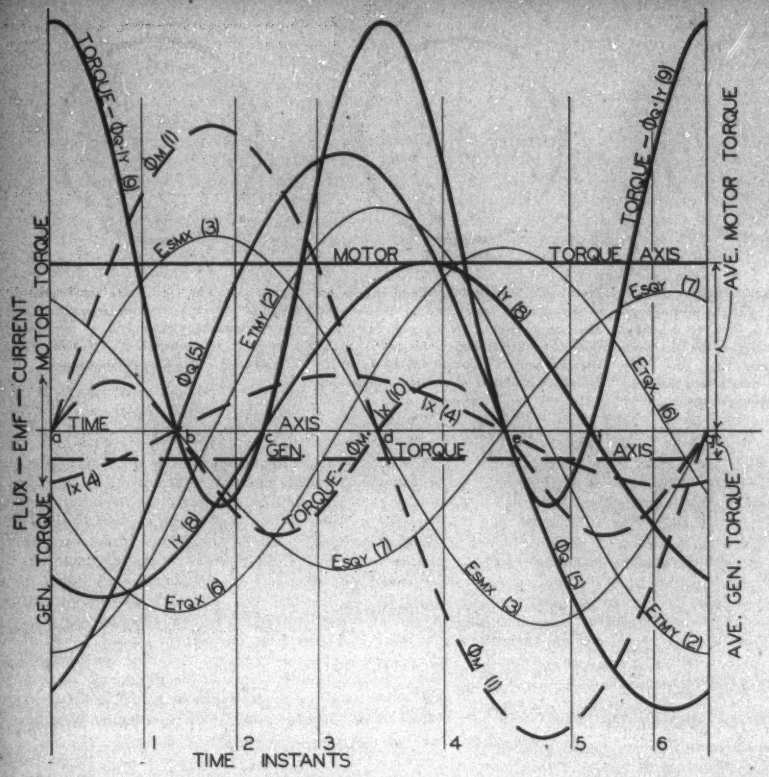


Figure 11. The complete time-phase diagram

The numbers on the curves indicate their order of explanation in the text and their order of development on the diagram, as well as serving as identification for reference

torque throughout a cycle of flux and current variation, as shown by curve (9). The average value of motor torque is found by obtaining the difference of the positive and negative areas, say in square-inch units, as taken between curve (9) and the time axis, and dividing this net area by the length of the base line from a to g, expressed in inches. This result in inches plotted vertically upward from the time axis locates the position of the motor-torque axis, and when translated into torque units, as were employed in plotting the torque curve, the distance of this new and displaced axis above the time axis represents the average motor torque. The value of the average motor torque is proportional to the product $\phi_Q \times I_Y \times \cos \theta_{IY}^{\phi Q}$. For this instantaneous or average motor torque to attain a maximum for a given magnitude of ϕ_Q and I_Y, two conditions of phase relationship are necessary. These are: (1) that quadrature space phase exist between the axis of the flux and the axis of the magnetomotive force of the current; and (2) that the time phase between the flux and the current be zero. The first requirement for optimum torque is completely satisfied at every instant in the single-phase induction motor, and the second is dependent upon the value of the cosine of the angle between the flux and current—which is a function of the load on the motor.

A much simpler construction for the motor-torque axis is to draw it as an axis of symmetry midway between the maxima of the torque curve $\phi_Q \times I_Y$ (9). With respect to this axis, the torque is seen to possess a double-frequency variation, developing principally motor torque whereby electrical power from the supply is transformed into mechanical power through the driving torque for the motor, but for short intervals of time, as between b and c and e and f, the rotor, in creating generator torque, yields electrical power to the electrical supply system.

THE AVERAGE GENERATOR TORQUE

Under the main poles the current-carrying conductors in which the quadrature field current I_X exists, as shown in the space-phase diagram, Figure 9, develop torque with the main field ϕ_M. As explained earlier, this torque at instant 1 was found to be motor torque. It is so plotted on Figure 10 for instant 1; and, the instantaneous products of the main field ϕ_M and the quadrature field current I_X throughout a cycle give curve (10) which is labeled "Torque—$\phi_M \times I_X$ (10)." The torque $\phi_M \times I_X$ becomes zero at the origin, instant a, when ϕ_M is zero, and it likewise becomes zero to the right of instant 1 at b when I_X is zero, as is apparent from an inspection of Figure 10. Between instants a and b this torque is proportional to

the instantaneous value of the product of ϕ_M and I_X, and it is of relatively small magnitude when compared to the main torque $\phi_Q \times I_Y$ for two reasons: (1) the quadrature field current I_X is small in comparison to I_Y, and (2) it lags ϕ_M by such a large time-phase angle that little average torque is developed.

The torque resulting from the reaction of ϕ_M and I_X changes from motor torque to generator torque at instant b, and it is generator torque between b and d, on Figure 10, because of the fact that the current I_X reverses its direction at b. The generator torque is represented in the downward direction, by adopted convention, between b and d. The area between this torque curve, $\phi_M \times I_X$ (10), and the datum time axis from b to d is obviously considerably greater than that under the same torque curve between a and b. At d the main field ϕ_M is seen to reverse polarity, the direction of the current I_X remaining unchanged, and thus the torque $\phi_M \times I_X$ reverses from its previous generator torque back to motor torque again. And later at e, the current I_X changes direction, and thus the torque changes again and becomes generator torque, remaining so between the time intervals e and g.

By following this torque curve $\phi_M \times I_X$ (10) throughout a cycle from a to g, it is seen to possess (1) a double-frequency variation, (2) an average value of generator torque, as the areas between the torque curve and the time axis are greater for generator action—b to d and e to g—than for those representing motor action—a to b and d to e, and (3) sine-wave symmetry about a displaced axis—the generator-torque axis—which is drawn midway between the maxima of the curve and whose displacement below the time axis is the measure of the average generator torque.

The composite and completed time-phase diagram showing the many correlated curves of fluxes, voltages, and currents for the rotor, as already presented by family groups in Figures 4, 6, and 10, is included here for reference as Figure 11. The four subordinate voltage curves are shown as light-weight lines, whereas the curves for ϕ_Q (5) and I_Y (8) and their product, the torque curve $\phi_Q \times I_Y$ (9), are drawn as heavy solid lines, and the curves for ϕ_M (1) and I_X (4) and their product, the torque curve $\phi_M \times I_X$ (10) are constructed as heavy dashed lines.

The instantaneous torques $\phi_Q \times I_Y$ and $\phi_M \times I_X$ may be independently determined at any other instants of time, as, for example, those shown as instants 2, 3, 4, 5, or 6 on Figure 11. The values of torque so determined obviously must be identical to those which have already been determined, that is, curves (9) and (10). The curves of flux, voltage, and current, in magnitude and in phase, when constructed for any other instant of time, will be found to be identical to those of Figure 11 regardless of the instant of time employed for their determination.

THE ROTOR CORE LOSS

The magnitude of the average generator torque is determined by the product of the in-phase component of the quadrature field exciting current I_X with the main field ϕ_M with which it reacts. If I_X should lag ϕ_M by 90 electrical degrees, then the torque curve $\phi_M \times I_X$ (10) would be disposed about the time axis so as to have equal areas representing motor and generator torque, and the average torque would be zero. Also, if the exciting current I_X were in lagging quadrature with ϕ_M and hence with E_{SMX} which produces it, it would develop zero average generator power with respect to E_{SMX}, as an inspection of Figure 11 substantiates. In this hypothetical case, there could be no iron losses in the rotor core resulting from the quadrature field.

Actually the current I_X is not quite in lagging quadrature phase with its speed voltage E_{SMX}, and thus it develops an average generator power just sufficient to supply the rotor core loss that results from the quadrature field. The average generator torque, as shown on Figure 11, at rotor speed, develops just the proper value of mechanical power to cause the rotor core loss to be supplied electrically. Since the quadrature field ϕ_Q is assumed to vary linearly with its field current I_X, then the rotor core loss, which is caused by it, decreases as a function of the increasing load on the motor, that is, an increasing load causes the speed to decrease, and with it E_{SMX}, I_X, ϕ_Q, and the rotor core loss all decrease.

Since the quadrature field ϕ_Q, as shown by Figure 7, has no net induction with the primary or any other winding, the question arises as to how the power necessary to supply this rotor core loss, resulting from the quadrature flux, is caused to flow into the motor. Because of the fact that this rotor core loss is supplied by the power generated within the rotor and developed by the average generator torque at the rotor speed, a small mechanical load is imposed upon the rotor as a result of it, and, hence, the motor runs at a slightly lower speed than it would if this loss did not exist. This reduction in speed causes the load current I_Y of the rotor to increase slightly and it is this current which reacts through its magnetomotive force on the stator windings. It causes an increment of input current into the stator winding, and together with a small improvement in its phase, it is just sufficient in magnitude to supply electrically the power for the rotor core loss.

For this reason, the speed of the single-phase motor at no load and under a hypothetical condition of zero friction and windage losses would be slightly below the synchronous value and by an amount just necessary to cause the rotor core loss to be supplied through the reflected load component of the power current I_Y in the stator winding. Under these same assumptions of no load and zero mechanical losses for the polyphase induction motor, it would run at exactly synchronous speed.

THE VECTOR DIAGRAM AND ITS ANALYSIS

Finally, the vector diagram is presented as a visual aid in showing the magnitudes and the phase relationships of the electric and magnetic quantities within the motor. The approximate vector diagram for the single-phase induction motor is shown in Figure 12. All quantities which occur in the stator winding are so designated by attaching to their symbols either a prime (′) or a subscript (1), otherwise the quantities are those occurring in the rotor. The symbols, together with their identifying subscripts, have already been explained, with the two exceptions of E_X and E_Y. The vector difference of the two voltage components E_{SMX} and E_{TQX} in those rotor inductors which are considered paired about the X axis, as their magnetic axis, is the leakage impedance voltage E_X. Likewise for those inductors paired about the Y axis, the vector difference of the two voltage components E_{TMY} and E_{SQY} is the leakage impedance voltage E_Y.

In this vector diagram as in the time-phase diagram of Figure 6, the quadrature field ϕ_Q has been drawn in phase with the exciting current I_X rather than in phase with its

magnetizing component which lags I_X by a small angle. By this simplification, unnecessary confusion of both diagrams is avoided; and, for the purpose of qualitative analysis, the variation with speed of the factors which determine the development of the motor and generator torques and power becomes more readily apparent.

As already explained, the components of leakage impedance of the rotor along the X axis are equal, respectively, to those along the Y axis, and hence the magnitude of either one of these impedance voltages depends upon the magnitude of the current causing it. The quadrature field exciting current I_X is slightly less than the exciting current I'_N for the stator field ϕ_M, and their ratio is equal to the ratio of ϕ_Q to ϕ_M. The current I_X lags the voltage E_X by the characteristic angle of the leakage impedance—an angle equal to that by which the load current I_Y lags its impedance voltage E_Y. Still assuming a linear magnetization curve, the load current I_Y varies proportionately with I_X as E_Y varies with E_X.

Since the stator field ϕ_M is considered constant, the quantities E_{SMX}, I_X, ϕ_Q, E_{TQX}, and E_X all vary in proportion to the speed. Hence as the speed of the rotor falls off with increasing load, both E_{SMX} and E_{TQX} decrease proportionately with the speed, and so then does the quadrature field current I_X and its field ϕ_Q. It should be observed that E_{TQX} is less than E_{SMX} at all speeds, including synchronous speed, by the amount of the vector difference of the leakage impedance voltage E_X. The average generator torque, $\phi_M \times I_X \times \cos \theta_{I_X \phi_M}$, decreases with the speed, and hence its developed mechanical power, which is the product of the torque and speed, decreases about as the square of the speed. This developed power is electrically the product of the in-phase component of the current I_X with its speed voltage E_{SMX}, a quantity which is also seen to vary about as the square of the speed.

The voltage E_{TMY}, which corresponds to the induced voltage E_2 in the secondary winding of a transformer, is independent of speed, but the countervoltage E_{SQY} varies about as the square of the speed. For decreasing values of rotor speed, the load current I_Y increases at a rate almost inversely proportional to the square of the speed—a relationship which is apparent from an inspection of the vector diagram, because the vector difference of E_{TMY} and E_{SQY} is roughly approximate, numerically, to their arithmetic difference. The average motor torque, $\phi_Q \times I_Y \times \cos \theta_{I_Y \phi_Q}$, increases for decreasing rotor speed for two reasons: (1) the load current I_Y increases more rapidly than the field ϕ_Q decreases with speed, and (2) the angle between ϕ_Q and I_Y decreases very appreciably with decreasing speed, thereby improving the power factor of the current. It is largely because of the latter effect that the developed motor power, which is the product of the average motor torque and speed, actually increases as the rotor speed decreases. This developed motor power may be expressed also as $E_{SQY} \times I_Y \times \cos \theta_{I_Y E_{SQY}}$, and so in this case the developed power increases for decreasing speed, largely because of the increased power factor, despite the fact that E_{SQY} decreases about as the square of the speed and I_Y increases, roughly, as the square of the speed.

This presentation has demonstrated the fact that, in the process of developing the cross-field theory of the single-phase induction motor, the concurrent construction of two fundamental diagrams is essential, namely, the space-phase diagram, Figure 9, including the transformer and speed voltages, and step by step with it, the time-phase diagram, Figure 11. While the vector diagram is a desirable visual aid to the final analysis of the magnitudes of the average generator and average motor torques and developed power, yet in the interests of clarity of presentation, the vector diagram should not be employed as a substitute for the time-phase diagram in attemping to explain the interactions of the fluxes and currents within the rotor.

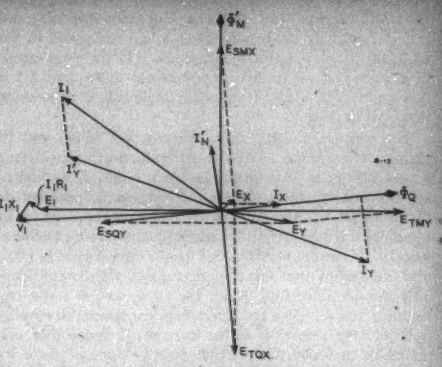


Figure 12. The time-phase vector diagram shows stator and rotor quantities

The positive projection of the quadrature field current I_X on its speed voltage E_{SMX} shows developed generator power to supply the rotor core loss, and the negative projection of the power current I_Y on its speed voltage E_{SQY} shows developed motor power

For simplicity of representation, the quadrature field ϕ_Q is shown in phase with the exciting current I_X rather than lagging it by the characteristic hysteretic angle

SUMMARY

In order to leave with the reader a critical appraisal of the correlated electric and magnetic quantities within the single-phase induction motor, the coexisting reactions of the magnetic fields, the voltages, and the currents are recapitulated here in simple form for final review.

1. The main field of the motor is created by the magnetomotive force developed within the stator winding by the magnetizing component of the stator current. Except for the relatively small changes in the magnitude of the main field which occur as the result of variations of the stator leakage impedance voltage with changing loads, the main field may be considered as reasonably constant—at least so for the purposes of this qualitative presentation.

2. Recognizing these minor variations in the main field, for the reasons as explained above, it may for all practical purposes be considered constant and, hence, independent of the variations in the speed of the motor. The stator field comes into being at the starting of the motor, but it, alone, develops no starting torque in reacting with the closed windings of the rotor. Actually to develop starting torque, the motor requires the addition of some form of auxiliary starting circuit and, in certain instances, associated mechanisms.

3. The main field causes three voltages to be developed, two by transformer action and one by speed action. One of the transformer voltages is induced in the stator winding. It is proportional to the mutual value of the stator field and to the equivalent number of turns in the stator winding; and, acting as a counter electromotive force to the applied voltage, this transformer voltage controls the

magnitude of the input current to the stator winding. The vector difference of the line voltage and this induced voltage is the stator leakage impedance voltage, as already mentioned.

4. The other voltages which are developed by the main field, another transformer voltage and the speed voltage, are established within the rotor windings.

5. The transformer voltage in the rotor has been identified throughout the text as E_{TMY}, and its magnitude is also proportional to the mutual value of the main field, as well as to the equivalent number of turns in the rotor winding. This is the largest of four voltages which are developed in the rotor windings, and its value is independent of speed to the same extent as is the main field which induces it. This voltage gives rise directly to the load current I_Y in the rotor, and this is the only component of current in the rotor which can interlink with and react upon the energized windings of the stator.

6. This voltage E_{TMY} and its component current I_Y are present in the rotor, when the stator winding is energized, whether the rotor is in rotation or not. At standstill, the load current causes no torque to be developed for the reason that its magnetic reaction with the main field lies in exact space phase with it, just as occurs in a transformer whose secondary winding is short-circuited.

7. As rotation occurs, a field is developed by the rotor winding which is in space quadrature and practically in time quadrature with the main field. This quadrature field causes the formation of poles on the stator whereby the rotor load current I_Y, reacting with this field, produces the driving torque of the motor.

8. The speed voltage generated in the rotor winding from the main field, when rotation occurs, is identified throughout the text as E_{SMX}. This voltage varies directly with the speed, being zero at standstill and a maximum at synchronous speed, and it is nearly equal in this latter case to the transformer voltage E_{TMY}. This speed voltage causes a magnetizing current I_X in the rotor winding which, in turn, brings into being the quadrature field.

9. The quadrature field alternates at line frequency, as does also the main field, but, assuming the magnetic structure to be operated on the linear part of the saturation curve, the magnitude of the quadrature field depends directly upon the value of the rotor speed, being zero at standstill and about equal to the main field at synchronous speed. By reason of its dependence upon the speed, this field could be called, and appropriately so, the "speed field."

10. As in the case of the main field, so does the quadrature field develop two voltages in the rotor winding—both counter voltages, one being a transformer voltage and the other a speed voltage. The transformer voltage, which is identified throughout the text as E_{TQX}, is induced in the same conductors as the speed voltage of the main field E_{SMX}, and, in consequence, it controls the magnitude of the quadrature field current I_X. The speed voltage, which is identified throughout the text as E_{SQY}, is generated in the same rotor conductors as the transformer voltage of the main field E_{TMY}, and hence, it controls the magnitude of the load current I_Y of the rotor.

11. The magnetizing current I_X is in those conductors which lie under the influence of the main field, and it develops torque with the main field which is found to be predominantly generator torque. This torque alternates at twice the line frequency and its graph is disposed symmetrically about a displaced torque axis which lies parallel to the time axis and which is drawn midway between its maxima and minima values. Its displacement from the time axis is proportional to the average generator torque. The torque curve, therefore, consists of a constant component—the average generator torque—and a superposed symmetrical double-frequency component.

12. The load produced by this average generator torque causes the motor to run at a speed slightly lower than it would otherwise do if this torque were not present. Because of this idiosyncrasy of the single-phase induction motor, the generator action, through the increased value of the load current I_Y, reflects itself into the stator circuit, and by this reaction, a small increment of input power, which is required to supply it, flows into the motor from the service mains.

13. The average generator torque, acting at rotor speed, develops mechanically the necessary power to supply the core loss of the rotor, a loss which occurs within the magnetic core of the rotor because of the flux variations of the quadrature field. As just stated, this power loss is supplied electrically from the service mains to the motor by the reaction of the reflected counter magnetomotive force of the increased load current I_Y.

14. Since the average generator torque is a direct function of the speed and since the power necessary to supply the rotor core loss varies both with the generator torque and with the speed, the rotor core loss varies about as the square of the speed. Hence, the rotor core loss, resulting from the quadrature field, is a maximum at synchronous speed and as the speed reduces, it decreases rapidly—a condition which is just opposite to that for the rotor core loss of the polyphase motor.

15. The load current I_Y, being in those conductors under the influence of the quadrature field, develops predominantly motor torque. This torque also alternates at double line frequency, and its graph is symmetrically disposed about a displaced torque axis which is drawn parallel to the time axis, and on the opposite side of the time axis from the average generator torque, so that it lies midway between the maxima and minima values of the motor-torque curve. Its displacement from the time axis is proportional to the average motor torque. This torque curve, like that for the generator torque, consists of a constant component and a double frequency component.

16. The value of the average motor torque depends upon the magnitude of the quadrature field, the value of the load current I_Y, and the cosine of the angle between them. The magnitude of the quadrature field varies about directly with the rotor speed. The load current, depending as it does upon the vector difference of the constant voltage E_{TMY} and the speed voltage E_{SQY}, which latter voltage is about proportional to the square of the speed, varies almost as the inverse square of the speed. The value of the cosine of the angle between the quadrature field and the load current increases very considerably with decreasing speed. From these variations, it can be seen that the average motor torque, within the normal operating range of the motor, increases, roughly, at a linear rate with decreasing speed.

17. The developed power of the motor, being proportional to the product of the load current I_Y, the speed voltage E_{SQY}, and the cosine of the angle between them, increases as the speed decreases, and this increase of developed power occurs largely through the improvement of the power factor of these two inter-reacting quantities.

18. Actually the generator torque and the motor torque occur as two components of a single combined net motor torque. During parts of the cycle this net torque acts as motor torque and at other parts of the cycle as generator torque. Such a widely variant behavior of the torque causes the speed of the motor to undergo slight cyclical variations. These speed variations are too small to have practical significance, although they are sufficient in magnitude to augment the otherwise noisy operation of the motor.

19. The double-frequency pulsations of the net torque in the motor cause it to develop an inherent noise during operation.[3] The noise occurs as the result of a double-frequency torsional vibration of electromagnetic origin which causes the stator to oscillate about the shaft of the motor as an axis. These torsional vibrations are transmitted in this manner to the base which supports the stator, and thereby, the noise is generated at the base of the motor.

REFERENCES

1. The Cross-Field Theory of Alternating-Current Machines, **H. R. West.** AIEE *Transactions*, volume 45, 1926, pages 466–74.

2. Performance Calculations on Induction Motors, **C. G. Veinott.** AIEE *Transactions*, volume 51, 1932, pages 743–55.

3. Single-Phase Motor-Torque Pulsations, **A. L. Kimball, Jr., and P. L. Alger.** AIEE *Transactions*, volume 43, 1924, pages 730–9.

III—Engineering: Handmaiden of Economics

C. W. KELLOGG
MEMBER AIEE

Third in a series, this article attributes past economic progress to the ways that have been devised by engineering to increase production for a given expenditure of effort. The author predicts that history will repeat itself and that engineering will continue to improve economic well-being as new frontiers are opened. These frontiers are in the realm of the human mind, to which there is no end nor limit, so long as men's imagination and enterprise remain unfettered to explore and extend them.

GOOD ENGINEERING should produce economically sound results, for engineering is but that group of special skills, knowledge, and experience whereby the forces of nature are made useful to mankind. If engineering projects are not economically sound they become a depressing rather than a stimulating influence on the general welfare.

The 30-year period now ending has seen economic miracles performed for the common man in the United States. By and large, the common man works for a living, otherwise he is uncommon. Based on the pay for an hour's work, the industrial worker today gets four times as much as he did 30 years ago. Yet, in the same period, the price of what he buys has gone up only one half, as measured by wholesale prices, and two thirds, as represented by the "cost of living." So he is relatively $3\frac{1}{2}$ times better off with respect to wholesale prices and $3\frac{1}{3}$ times better off with respect to living costs than he was in 1914. This great gain has been made entirely independent of the gold value of the dollar or any other variables, since the comparable factors before and after have been measured by the same yardstick at the same time. His gain is measured by the comparison between what he got for his work and what he paid for his wants at the same period.

If some industrial or engineering leader had in 1914 predicted that the then coming 30 years would produce for the common man the economic improvement that has in fact occurred, he would have been laughed at as a crazy optimist or criticized as a dangerous boat-rocker.

Since the human being himself was the same before as after, the miraculous improvement in his economic status has necessarily resulted from the more effective use of his time. This more effective use has been made possible by improved machinery, mass production, and mass sales. While a large part of this result has come from improved manufacturing methods, a substantial part of the credit must go to the engineers who have devised the processes and the machines for carrying them out.

Other countries have had their millions of common men, endowed with the same intelligence and potential ability as our own, yet they have made no such economic progress for their average citizen as we have. The magnitude of these differences was strikingly brought out by Gerard Swope, after a trip to Europe six years ago.* He gathered data from eight European countries (designated only by number) and obtained results like the following: The number of hours of work required to purchase a unit of five food items varied from 4.25 to 7.3 among the eight countries. In the United States it was 1.7. To buy an automobile took from 8.5 to 24 months' work in the European countries, compared to 4.5 in our country. In the matter of electricity, to purchase a kilo-watt-hour required from 12 to 43 minutes' work abroad, compared to 3.6 minutes at home. Finally, the acquisition of an incandescent lamp required from 1.2 to 3.4 hours of work from the European workman and only 0.2 hours here. These differences bring out the truly primary cause of the gains we have been able to show—the cause which brought out both the manufacturing and engineering triumphs of the last generation. I refer to the incentive to the exercise of initiative and courage which arises from freedom to make developments and the belief that economically effective pioneering will bring a compensatory reward.

It is essential to keep these fundamentals in mind in planning for the period after the war, because, when that longed-for time arises, we shall find basic things just as they always have been. People will still need their three meals a day, clothing and shelter, transportation and light, and other essential goods and services, and they will want as much more as they can economically get. With human nature and capacity unchanged, the only way by which the common man can rise to higher economic levels must be by his work being made more effective through the tools and methods which management and

C. W. Kellogg is president of the Edison Electric Institute, New York, N. Y.

* "Standards of Living," *The Atlantic Monthly*, March 1938.

invention may devise. Neither of these latter has ever flourished in the past except when and where the confidence of reaping adequate reward for special effort and risk was assured by the surrounding institutions. It should be stressed in passing that even the advantages arising from improved management and invention cannot be made completely effective without a marketing system adequate to dispose of the goods produced.

PURE SCIENCE AND APPLIED SCIENCE CONSTITUTE ENGINEERING

It has been the fashion for many years to attempt to draw a contrast between pure science and applied science, frequently, in the business mind, to the derogation of the former. In reality, they are but two parts of the same process of harnessing the forces of nature to the improvement of human life, wherein pure science furnishes the raw materials of fact and applied science the finished product made from those raw materials. One is just as essential as the other; engineering comprises both.

The history of electrical engineering is replete with the mutual dependence of these two factors. The great electric power industry of today rests squarely upon the raw-material fact, discovered by Faraday in 1831, that a closed conducting loop forced through a magnetic field produces an electric current in the circuit. Without this fact, the great present development could not exist; without the development, the fact would be but a laboratory stunt. It was discovered very early that an electric current passing through a conductor could heat it hot enough to emit light—a fact which became of transcendent importance when Edison, with a carbon filament operating in a vacuum, produced a light source that would not quickly burn itself out.

There is a close analogy in principle between the improvement in fuel economy of steam-driven prime movers and the gain in efficiency of electric-light sources since the early days. In each case, the early models wasted most of the energy put into them. In the case of the prime mover, the utilizable heat range (from the simple noncondensing engine to the modern turbine) has been magnified ten-fold; in the case of the light source (from the original carbon lamp to the modern fluorescent lamp) the usable light from a given energy input has likewise been increased ten-fold by eliminating the useless, because invisible, heat waves. Each step in this upward movement resulted from the application of the raw materials of discovered fact to practical application. Incidentally, household electric rates in the carbon-filament days were six times what they are today, although hourly labor costs are now four times as great.

The extraordinary gains in the economy of light sources have been the result of numberless engineering studies of details that would seem to the layman of minor importance. Lowering the absorption losses in glass from some 30 per cent to 10 per cent is one of these; another is the discovery that whether the crystals lie along or across the fine tungsten-wire filament means the difference between a relatively shock-resistant lamp or one that breaks easily.

Historically, the discovery of the electric arc considerably antedates the incandescent lamp. One of the earliest observations regarding this phenomenon was its very high temperature. This factual raw material is the basis for the modern electric furnaces, which in 1943 turned out nearly 8,000,000 tons of steel and ferroalloys. The great increase of electric steel capacity (six-fold in four years) has been due to the marked homogeneity of the product from electric furnaces and to the accuracy with which its composition can be controlled electrically. The consumption of electric energy in 1943, arising from this particular bit of factual raw material (8.3 billion kilowatt-hours) was about the same as was consumed 15 years ago by all the 19,000,000 homes in the United States which were then using electricity.

HISTORY CONTINUES TO REPEAT ITSELF

Attempting to look into the future on the basis of things just emerging, we see history repeating itself in the translation of laboratory knowledge into economic improvement. In some respects, electricity would seem to be the least economical source of heat for industrial processes. Yet it is precisely in the matter of heat that some of the most striking recent advances in industrial use have been developed. The really amazing economic results that have been achieved have arisen from the speed and concentrated application which electricity alone has made possible. High-frequency electric heat acts so quickly that tin can be successfully flowed on a sheet moving 1,000 feet a minute, and with dielectric high-frequency heating the time of setting glue in laminated structures has been reduced from six hours to 15 minutes.

It may prove to be good engineering to heat the human body for comfort rather than to expend fuel and capital in the heretofore common but inefficient means of air heating indoors. The same thing applies to cooking. We may justify projecting heat directly to the food rather than, as now, wastefully heating the whole kitchen. Perhaps it may turn out that our current methods of indoor heating are similar in economy to the process of "burning down the barn to get a mess of roast pork."

Engineering applied to translating electric energy into radiant energy with a wave length of 2,537 angstroms may mean fewer disease germs, sterile wounds, and lessened losses on foods from mold—all influences to lengthen human life. Engineering study of electric fields has led to the electric air filter. The economic value of dust-free air in saving maintenance cost and the endless drudgery of dusting and washing is at once apparent.

In all the illustrations I have cited, the ingenuity and imagination of the engineer have used the raw material of previously observed phenomena to produce practical results of definite economic worth.

STANDARDIZATION OFFERS ECONOMIES TO ELECTRIC UTILITIES

The electric-utility business is characterized by an especially high investment per dollar of annual gross revenue—about seven times as much as the average manufacturing industry. From this it follows that one of the most important problems facing that industry is that of keeping down or reducing the unit cost of utility-plant investment. The cost of the larger items of electric generating and translating equipment is greatly affected by the high overhead cost of special designs. Experience during the war has demonstrated that drastic cuts in cost could be effected as a result of the need for larger quantities of pieces of apparatus of which relatively

few were needed in peacetime. In fact, it was the drastic effect of the repetitive process on costs, compared to those based on previous manufacturing experience, that first called, from the manufacturers themselves, for renegotiation of war contracts.

For the future, a corresponding result can be obtained by the maximum amount of standardization of the major items of generating and transforming equipment. This has already been recommended by some of the larger manufacturers and is the subject of studies by committees of the engineering societies concerned. It is a consistent sequel to the recent war experience and to the nature of our past industrial development. The practical application of standardization calls for a statesmanlike co-operation between the designing engineers of the utilities and the production engineers of the manufacturers. The process is already under way; it should be progressively developed.

In recent years, perhaps the most conspicuous examples of engineering economics are the electrical interconnection of plants and systems, and topping turbines. The former effected economies in investment by making unnecessary many individual plant reserves formerly required, and in operating cost by maximum utilization of the most efficient plants. The latter has not only improved economy by enlarging the usable heat range, but has also lengthened the life of already existing units by bringing them usefully into the higher heat cascade.

NEW FRONTIERS—IN THE HUMAN MIND

Returning, in closing, to the thesis from which we started, our past economic progress has been largely due to the ways engineering has devised to enable the relatively changeless human faculties to get more effective results from a given human effort. After the war, progress must depend upon more development along those same lines. Much oratory and printers' ink have been expended lamenting the loss of the "frontier"—the physical frontier, whose extension, however, meant simply a wider area in which to exercise the same old human abilities as existed before the extension. The frontiers that have opened up in the last generation (after the *physical* frontiers had been pushed aside) have proved to offer much greater opportunities for improved economic well-being than the mere clearing of forests and settlement of land which were involved in the extension and final crossing of the last physical frontier.

These new frontiers are in the realm of the human mind, to which there is no end or limit, so long as man's imagination and enterprise remain unfettered to explore and extend them. In the field of electrical engineering this frontier country is particularly broad, rich, and inviting. May we, as a nation, have the good sense to realize that the effective area of our expansion territory, being of the mind and spirit, will depend predominantly upon the ability of mind and spirit to go forward in its exploration with perfect freedom!

Pennsylvania Trains Adopt Telephones

A two-way electronic train telephone system produced in co-operation with the Union Switch and Signal Company has been installed on the 67-mile Belvidere-Delaware branch of the Pennsylvania Railroad. The projecting bar behind the wheel of the freight locomotive (left) is the system receiving coil, and the equipment box is above the driving wheels. The headlight generator supplies electric power. In the cab are the telephone handset and the loudspeaker which reproduces signals from the block operators in wayside towers and the crew and conductor in the rear of the train. Communication with other trains in the system also is possible

INSTITUTE ACTIVITIES

Pacific Coast Technical Meeting Will Reflect Aircraft Interest

Arrangements are being made for an enlarged technical program for the Pacific Coast technical meeting, which will be held in Los Angeles, Calif., August 29–September 1. Meeting headquarters will be in the Biltmore Hotel.

Present indications point toward a program of approximately 20 technical sessions and conferences, at which some 50 technical papers will be presented during the four days of the meeting. Most of the sessions and papers will deal with electric equipment for military planes, because of the extent and importance of the aircraft industry on the Pacific Coast. Practically every phase of electrical applications to aircraft will be considered and there will be sessions on generators, motors, instruments, protective devices, radio-insulation problems, ignition, lighting, and maintenance. However, the program will not be devoted entirely to aircraft, as there will be a few papers in the central-stations field, which will discuss power generation, transmission, system stability, relays, and circuit breakers.

The personnel of the 1944 Pacific Coast technical meeting committee and chairmen of subcommittees is as follows:

T. M. Blakeslee, *general chairman;* E. S. Condon, *secretary-treasurer;* C. E. Baugh, M. M. Bridgwater, H. L. Caldwell, C. R. Davis, Fred Garrison, J. M. Gaylord, Thomas Ingledow, W. T. Johnson, A. O. Mangold, H. E. Mellrud, T. A. Robinson, E. W. Schilling, H. V. Strandberg; P. L. Johnson, *technical program;* G. R. Woodman, *registration;* R. F. Gheen, *hotel;* Bradley Cozzens, *arrangement;* Fred Foulon, aircraft activities; E. W. Morris, electronics activities; F. W. Maxstadt, *students activities;* A. D. Brown, *finance;* J. H. Vivian, *publicity;* P. L. Savage, *inspection trips;* and R. A. Hopkins, *educational.*

AIEE Board of Directors Meeting

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., May 25, 1944.

The board authorized the regular allowance for traveling expenses for a joint conference on student activities of Districts 8 and 9 and the University of British Columbia Branch, during the 1944 Pacific Coast technical meeting of the Institute in Los Angeles, Calif.

An appropriation of $9,430 was made for the presentation and publication of additional technical papers during the remainder of the present appropriation year, ending September 30, 1944. The additional funds were set aside at the recommendation of the technical program committee, which reported an increase in the number of papers over that estimated when the budget for the year was adopted, brought about principally by the large number of air transportation papers offered, as well as papers in the electrochemistry, electrometallurgy, welding, and industrial applications and control fields. All papers scheduled for regular sessions to date are considered by the respective technical committees to be important, and their presentation consistent with the board's wartime policy.

The national treasurer reported on the financial condition of the Institute for the fiscal year ending April 30, 1944, and the annual report of the board of directors, prepared under the direction of the national secretary, was approved for presentation at the annual meeting of the Institute, in St. Louis, June 26, 1944.

In accordance with section 37 of the constitution, the appointment of a national secretary for the administrative year beginning August 1, 1944, was considered. National Secretary H. H. Henline was reappointed.

Upon recommendation of the committee on planning and co-ordination, it was voted to hold the 1945 winter technical meeting of the Institute in New York, N. Y., January 22–26.

Upon recommendation of the vice-president of the Canada District (10), the Montreal Section, and the Sections committee, the maritime provinces of New Brunswick, Nova Scotia, and Prince Edward Island were added to the territory of the Montreal Section.

Upon recommendation of the standards committee, a revision of Part III—"Protection of Structures Containing Flammable Liquids and Gases" of the Code for Protection Against Lightning, was approved for submission to the American Standards Association as a revised American Standard. This was developed by sectional committee C5, Code for Protection Against Lightning, for which the AIEE and the National Bureau of Standards are joint sponsors. Participation with other organizations in the work of standardization of aeronautical electric equipment was authorized. Co-operation in a revision of the "Handbook of Interior Wiring Design" by the appointment of two representatives on the Industry Committee on Interior Wiring Design, was authorized. Appointment of Thomas Spooner as an additional AIEE representative on sectional committee Z32 "Graphical Symbols and Abbreviations for Use on Drawings" was approved.

The board approved the appointment by the president of the following committee of tellers to canvass and report on the ballots cast for the 1944 election of officers of the Institute:

R. C. Darrow (*chairman*), J. E. Burroughs, Franklin J. Johnson, Howard W. Meehan, E. K. Murphy, George T. Royden, and Charles H. Wagner.

The nomination of an AIEE representative for election by the board of trustees of the United Engineering Trustees, Inc., to The Engineering Foundation board for the four-year term beginning in October 1944, was referred to the president with power.

L. R. Mapes was reappointed an Institute representative on the Washington Award Commission for the two-year term beginning June 1, 1944.

Upon recommendation of the special committee on registration of engineers, the board voted not to approve the "Model Law for the Registration of Professional Engineers and Land Surveyors and Providing for the Certification of Engineers-in-Training," dated June 1943 and submitted by the American Society of Civil Engineers with a request for approval and endorsement.

As a result of a suggestion looking toward a continuing record of historical happenings in the fields of Institute activity, that is, carrying on the history of the first fifty years of the Institute contained in the Golden Anniversary issue of *Electrical Engineering* (May 1934), it was voted to request the technical program committee to review the past ten years and prepare a history of the high spots for publication in some future issue of *Electrical Engineering.*

Approval was given to a program, submitted by the Engineers' Council for Professional Development, for the accrediting, under the direction of the ECPD committee on engineering schools, of the curricula (non-degree) of technical institutes.

In response to a suggestion of the American Welding Society, the president was authorized to appoint a representative of the Institute on a proposed committee of representatives of various organizations to study the question of establishing agencies for the qualification of welding operators, for which there is a growing demand on the part of industry and public authorities.

The board appropriated $200 for the purpose of acquiring and distributing to electrical engineering students pamphlet copies of "The Second Mile—A Resurvey," by William E. Wickenden, in a manner to be determined by the committee on Student Branches.

Other matters were discussed, reference to which may be found in this or future issues of *Electrical Engineering.*

Other actions taken included the following:

Minutes were approved of the meeting of the board of directors held January 27, 1944, and the meeting of the executive committee April 26, 1944.

Recommendations adopted by the board of examiners at its meeting on May 18, 1944, were approved. The following actions were taken upon recommendation of the board of examiners: eight applicants were transferred to the grade of Fellow; 38 applicants were transferred, and 69 were elected to the grade of Member; 437 applicants were elected to the grade of Associate; one Member and one Associate were reinstated; and 319 Students were enrolled.

Disbursements were reported by the finance committee and approved by the board, as follows: February, $29,311.52; March, $25,216.34; April, $29,957.93; May, $30,739.02.

Those present were:

President—Nevin E. Funk, Philadelphia, Pa. *Past President*—David C. Prince, Schenectady, N. Y. *Vice-Presidents*—W. J. Gibson, Toronto, Ont., Canada; C. R. Jones, New York, N. Y.; K. B. McEachron, Pittsfield, Mass.; C. W. Ricker, New Orleans, La. *Directors*—T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa; K. L. Hansen, Milwaukee, Wis.; T. G. LeClair, Chicago, Ill.; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; W. R. Smith, Newark, N. J.; R. G. Warner, New Haven, Conn. *National Treasurer*—W. I. Slichter, New York, N. Y. *National Secretary*—H. H. Henline, New York, N. Y.

Contents of June 1944 Supplement Announced

The nine remaining technical papers presented at the 1944 AIEE winter technical meeting and not published in the monthly

Transactions sections of *Electrical Engineering* will appear in the June 1944 "Supplement to Electrical Engineering—Transactions Section" to be released shortly. The discussions of these papers and the discussions of the technical papers published in the January–June monthly sections also will be included in the supplement. This will complete the publication of papers and discussions presented at the New York winter meeting.

Copies of the supplement will be mailed shortly to those who entered advance orders. Others may obtain copies at 50 cents each from the AIEE order department, 33 West 39th Street, New York 18, N. Y., as long as the limited supply lasts.

The following papers which have been abstracted in *Electrical Engineering* will be printed in the supplement:

44-37—Effect of Altitude on Electric Breakdown and Flashover of Aircraft Insulation; *L. J. Berberich* (*M* '30), *G. L. Moses* (*A* '43), *A. M. Stiles* (*A* '43), *C. G. Veinott* (*M* '34). Abstracted in the January 1944 issue, page 26.

44-10—Transformer Magnetizing Inrush Currents and Influence on System Operation; *L. F. Blume* (*F* '30), *G. Camilli* (*F* '43), *S. B. Farnham* (*M* '42), *H. A. Peterson* (*M* '47). Abstracted in the December 1943 issue, page 546.

44-44—The Geometry of Arc Interruption—II. Current-Zero Phenomena; *E. W. Boehne* (*F* '43). Abstracted in the January 1944 issue, page 30.

44-62—Cost Study of 69- to 345-Kv Overhead Power-Transmission Systems; *J. G. Hehn* (*M* '29). Abstracted in the January 1944 issue, page 30.

44-40—The Capacitor—an Aid to Electric-Power Service for Pipe Lines; *M. A. Hyde* (*A* '27), *R. E. Marbury* (*M* '35). Abstracted in the January 1944 issue, page 28.

44-53—Current Rating of Cables as Affected by Mutual Heating in Air or Conduit; *committee on research, Insulated Power Cable Engineers Association.* Abstracted in the January 1944 issue, page 29.

44-38—Electric-Circuit Fault-Protective Principles as Applied to D-C Aircraft Systems; *R. H. Kaufman* (*M* '41). Abstracted in the January 1944 issue, page 27.

44-17—Lightning Protection for Rotating Machines; *G. D. McCann* (*M* '44), *E. Beck* (*M* '35), *L. A. Finzi* (*A* '40). Abstracted in the December 1943 issue, page 547.

44-61—Electric Equipment for the War Emergency Pipe-Line Projects; *E. E. Thomas* (*M* '29), *W. G. Taylor, Oscar Wolfe.* Abstracted in the January 1944 issue, page 28.

Officers for 1944–45 Announced at St. Louis Meeting

Institute officers for the year beginning August 1, 1944, were announced in the report made by the committee of tellers to the annual meeting of the AIEE held June 26, during the summer technical meeting in St. Louis, Mo. The new officers are:

President: Charles A. Powel, manager, headquarters engineering departments, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Vice-Presidents: R. T. Henry, assistant chief electrical engineer, Buffalo (N. Y.), Niagara and Eastern Power Corporation (District 1, North Eastern); J. F. Fairman, assistant vice-president, Consolidated Edison Company of New York (N. Y.) Inc. (District 3, New York City); M. S. Coover, professor and head of the department of electrical engineering, University of Iowa, Ames (District 5, Great Lakes); R. W. Warner, professor and head of the department of electrical engineering, University of Texas, Austin (District 7, South West); C. B. Carpenter, assistant chief engineer, general engineering department, Pacific Telephone and Telegraph Company, Portland, Ore. (District 9, North West).

Directors: P. L. Alger, assistant to the vice-president in charge of engineering, General Electric Company, Schenectady, N. Y.; M. J. McHenry, director of sales promotion, Hydro-Electric Power Commission, Toronto, Ont.; D. A. Quarles, director of transmission development, Bell Telephone Laboratories, Inc., New York, N. Y.

Treasurer: W. I. Slichter, professor emeritus of electrical engineering, Columbia University, New York, N. Y.

The board of directors for the administrative year beginning August 1, 1944, will consist of the foregoing elected officers and the following holdover officers:

Nevin E. Funk, Philadelphia, Pa. (*retiring president*); H. S. Osborne, New York, N. Y. (junior past president); L. A. Bingham, Boulder, Colo.; J. M. Gaylord, Los Angeles, Calif.; W. J. Gilson, Toronto, Ont.; C. W. Ricker, New Orleans, La.; W. E. Wickenden, Cleveland, Ohio (*vice-presidents*); L. R. Gamble, Spokane, Wash.; K. L. Hansen, Milwaukee, Wis.; C. M. Laffoon, East Pittsburgh, Pa.; T. G. LeClair, Chicago, Ill.; F. R. Maxwell, Jr., Pensacola, Fla.; C. W. Mier, Dallas, Tex.; S. H. Mortensen, Milwaukee, Wis.; W. B. Morton, Philadelphia, Pa.; W. R. Smith, Newark, N. J. (*directors*).

A detailed report of the summer technical meeting at St. Louis, Mo., is scheduled for the August issue.

National and District Prizes Awarded at Summer Meeting

Announcement of the 1943 recipients of the national prizes for the best papers in four fields was made by F. A. Cowan, chairman of the AIEE committee on award of Institute prizes and presentation of the prizes was made by AIEE President Nevin E. Funk on June 26 at the annual meeting of the Institute in St. Louis, Mo. As in 1940, 1941, and 1942 no award was made for 1943 in the field of public relations and education because no eligible papers were presented.

The selections of the committee were:

Best Paper in Engineering Practice: Prize awarded to L. R. Ludwig (*M* '41) and W. M. Leeds (*M* '38) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for their paper, "A Multiorifice Interrupter for High-Voltage Oil Circuit Breakers," presented at the 1943 national technical meeting, January 25–29, and published in the 1943 *Transactions*, pages 119–25. Honorable mention was awarded to L. O. Grondahl (*M* '42) and P. N. Bonsart of the Union Switch and Signal Company, Swissvale, Pa., for their paper, "Train Communication," presented at the 1943 North Eastern District meeting, April 8–9, and at the 1943 South West District meeting, April 26–30, and published in the 1943 *Transactions*, pages 493–500.

Best Paper in Theory and Research: Prize awarded to B. R. Teare, Jr. (*F* '42) and Mrs. J. R. Webb (*A* '41) of the Carnegie Institute of Technology, Pittsburgh, Pa., for their paper, "Skin Effect in Bimetallic Conductors," presented at the 1943 national technical meeting, January 25–29, and published in the 1943 *Transactions*, pages 297–301. Honorable mention was awarded to R. V. Shepherd (*M* '43) and C. E. Kilbourne (*M* '37) of the General Electric Company, Schenectady, N. Y., for their paper, "The Quadrature Synchronous Reactance of Salient-Pole Synchronous Machines," presented at the 1943 national technical meeting, June 21–25, and published in the 1943 *Transactions*, pages 684–89.

Initial Paper: Prize awarded to Fred Foulon (*F* '42) of the Douglas Aircraft Company, El Segundo, Calif., for his paper, "Radio-Noise Elimination in All-Metal Aircraft," presented at the 1943 national technical meeting, September 2–4, and published in the 1943 *Transactions*, pages 877–91. Honorable mention was awarded to H. H. Fahnoe (*A* '35) of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., for his paper, "A New High-Interrupting-Capacity Fuse for Voltages Through 138 Kv," presented at the 1943 national technical meeting, June 21–25, and published in the 1943 *Transactions*, pages 630–35.

Branch Paper: Prize awarded to R. W. Cronshey (Enrolled Student) of the Michigan College of Mining and Technology, Houghton, for his paper, "A Simple Graphical Method for Calculating Antenna Radiation Patterns," presented at a meeting of the college Student Branch, January 27, 1943.

DISTRICT PRIZES

District prizes for AIEE papers have been announced by seven Districts. The awards are for papers presented during 1943, except Branch papers, which were presented during the academic year ending June 30, 1943.

District 1

Prize for best paper was awarded to S. Minneci (*A* '38) and S. B. Farnham (*M* '42) for their paper "A New Control System for Automatic Parallel Operation of Load-Ratio-Control Transformers," presented at the North Eastern District technical meeting, Pittsfield, Mass., April 8–9, 1943.

District 2

Prize for best paper was awarded to B. R. Teare, Jr. (*F* '42) and Josephine R. Webb (*A* '41) for their paper "Skin Effect in Bimetallic Conductors," presented at a meeting of the Pittsburgh Section, February 14, 1943.

Prize for initial paper was awarded to H. C. Marcroft (*A* '31) for his paper "Use of Dielectric Absorption Tests in Drying Out Large Generators," presented at a meeting of the Maryland Section, April 5, 1943.

District 5

Prize for Branch paper was awarded to R. W. Cronshey (Enrolled Student) for his paper "A Graphical Method for Calculating Antenna-Radiation Patterns," presented at a meeting of the Michigan College of Mining and Technology Branch, January 27, 1943.

District 6

Prize for best paper was awarded to L. M. Robertson (*M* '38) for his paper "Electric Performance and Investigations at High Altitudes," presented at a meeting of the Denver Section, October 15, 1943.

Prize for Branch paper was awarded to R. J. Carlson (Enrolled Student), G. L. Harvey (Enrolled Student), and W. H. Clark, for their paper "A Two-Speed A-C Generator," presented at a meeting of the University of Denver Branch, April 27, 1943. Honorable mention for this prize was given to C. A. Stutt, for his paper "Experiences With a D-C Calculating Board," presented at a meeting of the University of Nebraska Branch, April 14, 1943.

District 7

Prize for Branch paper was awarded to J. N. Leedom (*A* '44) for his paper "Ultrahigh-Frequency Transmission in Hollow Guides," presented at a meeting of the Rice Institute Branch, March 1, 1943.

District 8

Prize for best paper was awarded to Fred Foulon (*N* '42) for his paper "Radio-Noise Elimination in All-Metal Aircraft," presented at the National technical meeting, Salt Lake City, Utah, September 2–4, 1943.

District 10

Prize for best paper was awarded to A. E. Davison (*A* '13) for his paper "Meteorological Services for Designers and Operators of Electric-Power Systems," presented at a meeting of the Toronto Section, October 25, 1943.

Prize for initial paper was awarded to C. A. Laverty (*A* '33) for his paper "Causes and Effects of Damage to Electrical Machinery and Switching Equipment," presented at a meeting of the Toronto Section, November 12, 1943.

Additions to List of Members for Life

Membership for life is granted by the AIEE to members who either have paid annual dues for 35 years, or have reached the age of 70 and paid dues for 30 years. A list of those who have become members for life during the preceding year is published annually in *Electrical Engineering*. Institute members who have attained this status since publication of the last list in the July 1943 issue are:

L. F. Adams	H. C. Bartholomew
D. J. Angus	F. G. Beetem
R. W. Atkinson	H. C. Blackwell
A. Ball	O. B. Blackwell
S. Barfoed	L. F. Blume
C. J. Barrow	L. N. Bolsen

F. C. Bolton
W. T. Booth
H. V. Bozell
O. C. Brill
S. N. Castle
L. W. Chubb
F. W. Cloud
W. D. Coolidge
M. Cornelius
I. L. Craig
E. J. Crawford
W. A. Darrah
E. G. Davis
H. P. Dodge
C. E. Drennen
A. M. Dudley
A. J. Duncan, Jr.
H. E. Dunham
H. E. Dyche
E. J. Edwards
H. E. Eisenmenger
L. S. Ford
E. H. Freeman
W. W. Gaskill
I. H. Gatkin
A. S. Glasgow
C. Goldsmith
V. Greiff
F. G. Hamilton
J. D. Harnden
F. E. Haskell
J. W. Herman
W. G. Hewson
H. H. Higbie
V. L. Hollister
B. D. Horton
P. J. Howe
A. H. Hull
D. J. Hutton
J. G. Jackson
A. N. Johns
C. A. Johnson
C. E. Johnson
J. C. Jones
J. E. Kearns
C. H. Keel
W. G. Kelley
J. N. Kelman
E. H. Kifer
J. Klemm
O. A. Knopp
C. le Maistre
H. Lippelt
E. A. Loew
M. H. Logan
H. C. Louis
B. S. Luther
R. B. MacGuinness
G. K. Manson
A. C. Marshall
J. C. Marshall
C. L. Matthews
G. W. McIver, Jr.
W. J. McKeen
F. W. Merrill
J. L. Merrill
L. T. Merwin
J. W. Morrison
J. Morse
S. H. Mortensen
H. Mouradian
J. A. Moyer
A. Mullhaupt, Jr.
E. J. Nathan
E. E. Nelson
F. Oppenheimer
D. P. Orcutt
O. W. Paddock
R. G. Parrott
B. H. Peck
H. B. Peirce
C. S. Peters
E. W. Pragst
C. L. Proctor
R. J. Randolph
C. R. Reid
S. Ring
E. B. Rollins
G. W. Saathoff
D. R. Shearer
O. F. Shepard, Jr.
W. M. Shepard
J. W. Shuman
T. Smith
E. S. Steinbach
W. Sykes
W. S. Taussig
H. Thomas
A. I. Totten
M. Unger
H. R. Van Deventer
R. S. Wallace
G. A. Waters
G. G. Watson
L. R. Waugh
E. Weber
F. D. Weber
D. S. Wegg
A. C. Wood
E. M. Wood
C. D. Woodward
E. B. Woodward
C. E. Young
F. Zogbaum

These members of the Philadelphia Section received special prizes for faithful attendance at meetings throughout the year. Shown with their prizes, they are left to right, standing: J. D. Wood (M '27), A. E. Pringle (A '36), and H. S. Phelps (A '21); second row: L. R. Baker (A '43), and Frank McDonald (A '38); and foreground: N. R. Cox (M '43), L. Haines (A '17), and A. C. Finney (A '07)

SECTION • • • • •

Philadelphia Section Elects Executive Officers for 1944–45

The Philadelphia Section of the AIEE, meeting at the Engineers Club on May 8, 1944, for the last session of the season, approved a revision in the bylaws to permit the organization of Subsections. Also accomplished during the business of the meeting was the election of executive officers for the 1944–45 season. They are:

Chairman, A. C. Muir (M '39) electrical engineer, Berwind-White Coal Mining Company.

Vice-chairman, C. T. Pearce (M '40) Middle Atlantic engineering and service manager, Westinghouse Electric and Manufacturing Company.

Secretary, M. L. Lehman (M '36) project engineer, Philadelphia Electric Company.

The prize-papers committee, under the chairmanship of L. E. Howard (A '40), awarded cash prizes to C. S. Schifreen (M '43), O. B. Vikoren (M '43), and H. C. Warner, for the best papers entered in the Section prize-paper competition. Two of the winning papers were presented to the meeting.

Mr. Schifreen, discussing "Fatigue of Lead Sheath on Underground Cable," reported that failure records of large mileages of cable indicate that ratings are limited much more by the physical proportionments than by inherent weaknesses in insulation or sheath. To support this claim he presented the results of accelerated tests in a unique full-scale dummy manhole and duct run, which indicated the relationships of loading, conductor temperature changes, and movement in manholes and ducts to sheath life. The paper suggested a method of computing life expectancy for different loadings as a function of manhole dimensions.

"Transformer Arrangements for Large Motor Loads," by H. C. Warner, considered the problems encountered in the design of a large pumping station, particularly with respect to the best voltage ratings of the motors and co-ordinated switching and starting equipment. It presented a method for solving such problems, and for obtaining a simple reliable system that will utilize standard equipment with high efficiency, low capital investments, and low maintenance costs. Both papers were accompanied by slides illustrating the features outlined.

As a grand finale a large number of special prizes were distributed for faithful attendance at Section meetings throughout the season.

STANDARDS • • •

AIEE to Participate in Aeronautical Standardization

Remarkable strides have been made in the development of electric equipment for aeronautical purposes. The Institute, with its broad background of knowledge and experience in the preparation of electrical Standards, plans to participate to the fullest extent possible in the preparation of aeronautical electric-equipment Standards. To date, much of the standardization work on aeronautical equipment has been carried on under the auspices of Society of Automotive Engineers and the National Aircraft Standards Committee.

At the AIEE Standards committee meeting, May 23, 1944, it was decided that the assistance of the Institute in this work should be offered to the NASC and the SAE. This has been done, and these organizations desire to take full advantage of the possibilities. It is believed that the Institute can be particularly helpful in formulating fundamental electrical Standards including performance characteristics of aeronautical electric equipment and devices, test codes, and methods of demonstrating specified performance, and methods of calculation.

New Standard. American Standard *C* 62.1, "Lightning Arresters for A–C Power Circuits," which is a revision of the AIEE and American Standard 28, has been approved. It applies to all types of lightning arresters designed for a-c circuits having an element with nonlinear volt-ampere characteristic to limit the current. The Standard is 30 cents per copy with 50 per cent discount to AIEE members on single copies.

Future AIEE Meetings

Pacific Coast Technical Meeting
Los Angeles, Calif., Aug. 29–Sept. 1, 1944

PERSONAL ••••

L. R. Ludwig

Fred Foulon

W. M. Leeds

L. R. Ludwig (A '28, M '41) manager of the motor division, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1943 best paper prize in engineering practice as coauthor of the paper, "A Multiorifice Interrupter for High-Voltage Oil Circuit Breakers." Mr. Ludwig was graduated from the University of Illinois in 1925 with the degree of bachelor of science in electrical engineering. Employed by the Westinghouse company as a graduate student in 1925, he worked as assistant to the chief electrical engineer from 1926 to 1928 and in the latter year was transferred to the railway motor engineering department. He became section engineer in the research laboratory in 1930, manager of circuit-breaker and protective-devices engineering in 1935, and manager of the motor division in 1944. As the recipient of the first Benjamin Lamme scholarship he studied at the University of Berlin in 1929–30. He was coauthor of the paper receiving the national best paper prize in the field of theory and research in 1934 and received honorable mention for his paper in that field in 1935.

W. M. Leeds (A '32, M '38) electrical engineer, switchgear engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1943 national best paper prize in engineering practice as coauthor of the paper "A Multiorifice Interrupter for High-Voltage Oil Circuit Breakers." He received the degree of bachelor of science from Haverford College in 1926 and that of master of science from the University of Pittsburgh in 1930. Mr. Leeds has been associated with the Westinghouse Company since 1927 first as engineer in the circuit breaker engineering division and since 1939 in the switchgear engineering department. In 1937 he was awarded the Benjamin Lamme scholarship for graduate study and spent one year at Massachusetts Institute of Technology, Cambridge. He is a member of Phi Beta Kappa and Sigma Xi.

B. R. Teare, Jr. (A '29, F '42) professor of electrical engineering, Carnegie Institute of Technology, Pittsburgh, Pa., has been awarded the 1943 national best paper prize in theory and research as coauthor of the paper, "Skin Effect in Bimetallic Conductors." This paper also was awarded the 1943 best paper prize by District 2. He received from the University of Wisconsin the degrees of bachelor of science in 1927 and master of science in 1928 and from Yale University the degree of doctor of engineering in 1937. He entered the employ of the General Electric Company, Schenectady, N. Y., in 1928 and until 1933 worked in the testing department, the research laboratory, and the general engineering department. Joining the faculty of Yale University, New Haven, Conn., as instructor in electrical engineering in 1933 he was named assistant professor in 1934. Since 1939 Doctor Teare has been associated with the Carnegie Institute of Technology as professor of electrical engineering. He is a member of the Society for the Promotion of Engineering Education and of the Institute of Radio Engineers.

Josephine R. Webb (A '41) development engineer, power circuit breaker department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been awarded the 1943 national best paper prize in theory and research as coauthor of the paper, "Skin Effect in Bimetallic Conductors." This paper also was awarded the District 2 prize for best paper for 1943. Mrs. Webb received the degree of bachelor of science in electrical engineering from Purdue University in 1940. In 1940 she was employed as technical assistant at Carnegie Institute of Technology, Pittsburgh, Pa., and in 1942 entered the employ of the Westinghouse Company for which she worked first in the ignitron research laboratory.

Fred Foulon (A '30, M '42) electrical engineer, engineering department, El Segundo (Calif.) plant, Douglas Aircraft Company, has been awarded the 1943 national prize award for best initial paper for his paper, "Radio-Noise Elimination in All-Metal Aircraft." This paper also was awarded the District 8 prize for best paper of 1943. Mr. Foulon received the degree of bachelor of science in engineering from the University of California in 1928 and the degree of master of science in electrical engineering from the California Institute of Technology in 1932. After a short time in the test department of the San Diego (Calif.) Consolidated Gas and Electric Company, he joined the Electrical Research Products Company, Seattle, Wash., as supervising engineer in 1929. He was engineer in the sound department of Warner Brothers Pictures, Hollywood, Calif., from 1933 to 1937 and in the sound department of Universal Pictures, Hollywood, in 1937. He joined the Douglas Aircraft Company in 1938 as research analyst.

R. W. Cronshey (Enrolled Student) lieutenant in the United States Army Signal Corps, has been awarded the 1943 national prize award for Branch paper for his paper, "A Simple Graphical Method for Calculating Antenna Radiation Patterns." This paper also was awarded the District 5 prize for best Branch paper for 1943. Lieutenant Cronshey was born in Newark, N. J., May 14, 1918. Before entering Michigan College of Mining and Technology in 1938, he worked in the laboratory of the Western Electric Company, Kearny, N. J. While attending college, from which he graduated with the degree of bachelor of science in electrical engineering in 1943, he was chief operator for radio station W9YX and also instructed a class in amateur radio. In 1943 he was commissioned a second lieutenant in the Signal Corps. For a time he was stationed at Fort Monmouth, N. J., and is currently serving overseas. He is a member of Eta Kappa Nu and Tau Beta Pi.

L. O. Grondahl (A '26, M '42) director of research and engineering, Union Switch and Signal Company, Swissvale, Pa., has received honorable mention in the 1943 national prize award for the best paper in engineering practice as coauthor of the paper, "Train Communication". Doctor Grondahl holds the degrees of bachelor of science (1904) from St. Olaf College and of master of science (1905) and doctor of philosophy (1908) from Johns Hopkins University. In 1940 he was awarded the honorary degree of doctor of science by the latter. He served as lecture assistant at Johns Hopkins University, Baltimore, Md., in 1906 and instructor in physics at Spokane (Wash.) College in 1908, and at the University of Washington, Seattle, in 1909. He joined the Carnegie Institute of Technology as instructor in 1912, becoming assistant professor in 1914, and associate professor in 1917. Since 1920 he has been director of research for the Union Switch Company and in 1937 was named director of research and engineering. He holds numerous patents.

R. V. Shepherd (A '36, M '43) electrical engineer, motor and generator engineering department, General Electric Company, Schenectady, N. Y., has received honorable mention in the national prize award for the best paper in the field of theory and research as coauthor of the paper, "The Quadrature Synchronous Reactance of Salient-Pole Synchronous Machines." A 1935 graduate of the University of Illinois Mr. Shepherd immediately entered the test department of the General Electric Company and in 1937 was transferred to the motor and generator engineering department.

C. E. Kilbourne (A '29, M '37) designing engineer, motor and generator engineering department, General Electric Company, Schenectady, N. Y., has received honorable

R. W. Cronshey

Josephine Webb

B. R. Teare, Jr.

mention in the national prize award for the best paper in the field of theory and research as coauthor of the paper, "The Quadrature Synchronous Reactance of Salient-Pole Synchronous Machines." Mr. Kilbourne received his bachelor of science degree from Virginia Military Institute in 1927 and his professional engineering degree from that institution in 1931. He entered the test department of the General Electric Company in 1927 and the a-c engineering department which later became the motor and generator engineering department in 1929

H. H. Fahnoe (A '35) design engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has received honorable mention in the national prize award for best initial paper for his paper, "A New High-Interrupting-Capacity Fuse for Voltages Through 138 Kv." A 1934 graduate of Cornell University, Mr. Fahnoe joined the Westinghouse Company as a graduate student in 1935 and was named design engineer in 1936.

J. P. McKearin (A '11, F '38) chief engineer, Western Massachusetts Companies, Springfield, has retired. He commenced his career as station operator for the Vermont Marble Company in 1905 and became construction foreman for the General Electric Company, Schenectady, N. Y., in 1906. He was transferred, as engineer, to the company's district office in Boston, Mass., about 1910 and became assistant district engineer in 1913. In 1917 he joined the United Electric Light Company, Springfield, as electrical engineer and in 1927 was employed by the Western Massachusetts Companies. Since 1932 he had been chief engineer. **J. W. Bennett** (A '26, M '29) assistant chief electrical engineer, succeeds Mr. McKearin. Mr. Bennett was commercial engineer for the Central Hudson Gas and Electric Company, Newburgh, N. Y., in 1924 and joined the Eastern New Jersey Power Company, Asbury Park, as distribution engineer in 1925. In 1930 he was made distribution engineer for the Western Massachusetts Companies and in 1939 was appointed assistant chief electrical engineer.

A. L. Cook (A '02, M '13) director of the school of science and technology, Pratt Institute, Brooklyn, N. Y., has retired. Mr. Cook holds the degrees of bachelor of science (1901) and master of science (1903) from Worcester Polytechnic Institute. He was associated first with Pratt Institute as instructor in charge of the electrical laboratory from 1903 to 1907. After serving as electric power engineer for Westinghouse, Church, Kerr and Company, New York, N. Y., from 1907 to 1913, he returned to Pratt Institute as head of the electrical department. In 1938 he became director of the school of science and technology. He is the author of several textbooks and a member of the Society for the Promotion of Engineering Education.

H. V. Erben (M '43) formerly manager of the central station divisions, General Electric Company, Schenectady, N. Y., has been elected a commercial vice-president. A graduate of the Sheffield Scientific School, Yale University, Mr. Erben joined the General Electric Company in 1917. After service with the United States Army he entered the testing department in 1920 and in 1922 was transferred to the lighting engineering department. He was made section head of the apparatus division in 1923, assistant to the manager of the division in 1928, and manager in 1929. He was appointed manager of switchgear sales in 1933 and assistant manager of the central-station divisions in 1939. In 1941 he became manager.

H. J. Gille (A '01, M '13) manager of industrial and agricultural development, Puget Sound Power and Light Company, Seattle, Wash., recently retired. Mr. Gille entered the electrical field in 1890 when he was employed by the Acme Electric Company, St. Paul, Minn., and in 1898 became general superintendent of the Edison Electric Light and Power Company, St. Paul. He joined the Minneapolis General Electric Company, St. Paul, in 1907 and the Puget Sound Company in 1913 as general sales manager. In 1932 he was made manager of industrial and agricultural development.

R. C. Faught (A '19) sales engineer, General Electric Company, Baltimore, Md., has retired. Mr. Faught was graduated from the Massachusetts Institute of Technology in 1894 and entered the employ of the General Electric Company in 1898 as test man. Since 1900 he has been engaged in sales engineering. He was stationed in Philadelphia, Pa., in 1900, in Richmond in 1902, and in Baltimore in 1903. Except during World War I when he had charge of the company's Washington, D. C., office, he has remained at Baltimore since.

OBITUARY ••••

Stephen S. Darrall (A '41) member of the United States Merchant Marine was reported lost at sea in September 1943. Mr. Darrall, who was born August 29, 1882, in Irwin, Pa., commenced electrical work as an engineering apprentice for the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1902 and was transferred to New York, N. Y., to do construction, erection, and electrical servicing in 1904. Going to Iniwue, Chile, in 1907 he was employed in electrical engineering, sales, and construction for J. K. Robinson, Westinghouse agent in Chile, Peru, Bolivia, and Ecuador. He served aboard the S.S. *Minnesota* in 1914 before entering the employ of the Kennecott Corporation, Latouche, Alaska, as chief electrician. As chief electrician he also worked for the Pacific Coast Gypsum Company, Gypsum, Alaska, from 1917 to 1919. In 1919 he entered the district service department of the Westinghouse company in Seattle, Wash. He was superintendent of electrical construction for the Long Bell Lumber Company, Longview, Wash., from 1923 to 1925 and for the San Francisco Mines of Mexico, Parral, Chihuahua, Mex., in 1926 and 1927. Returning to the United States he was employed in the district service department of the General Electric Company in 1928 and of the Westinghouse Company in 1929. From 1931 to 1941 he was employed at various engineering projects, mechanical and civil as well as electrical. In 1941 he was employed on the national defense program at the Boston Yards of the United States Navy. He resigned in 1943 to join the merchant marine.

William McNichol Eglinton (A '03) second-hand-machinery and fire-insurance broker, Santiago, Chile, died August 4, 1943. He was born May 14, 1867, in Glasgow, Scotland, and gained his electrical training in the experts course of the Thomson-Houston Electric Company in 1888 and 1889 and in the student course of the General Electric Company at Schenectady, N. Y., and Lynn, Mass., in 1899. From 1889 to 1893 he worked as draftsman and foreman in Venezuela and in 1893 joined the Maracaibo (Venezuela) Electric Light Company as chief engineer and electrician. In 1901 he became constructing engineer and technical director for the South Puerto Rican Sugar Company. Later he was associated with the Electric Company of Concepcion (Chile) until 1910. For a time he was consulting and constructing engineer in New York, N. Y., and in 1912 was employed as engineer by the International Machinery Company, Santiago, Chile. He became manager of the Industrial Supplies Company, Santiago, in 1920 and manager of the machinery department, Errazuriz Simpson and Company, Ltd., Santiago. From 1926 to 1929 he was sales engineer for Wassel, Duval and Company, Santiago, and for the Allis-Chalmers Manufacturing Company from 1929 to 1936. He established a consulting practice in 1936 and a brokerage in 1940.

Cyril Cochrane Levy (A '33) industrial engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and 1943–44 chairman of the AIEE committee on electrochemistry and electrometallurgy, died June 5, 1944. Mr. Levy was born September 18, 1886, in Lucea, Jamaica, B. W. I., and attended Toronto University. His first position in the electrical industry was switchboard operator for the New York (N. Y.) Edison Company in 1905 and 1906. During 1912–13 he worked as electrical draftsman for the Canadian General Electric Company, Toronto, Ont. As switchboard draftsman he joined the Westinghouse Company in 1913 and from 1916 to 1920 he was designing engineer in the switchboard department. In 1920 he was placed in charge of switchboard drafting and in 1922 became automatic switching engineer. Since 1930 he has been engaged in application engineering specializing in electrochemical and chemical industries. Mr. Levy had served on the committee on electrochemistry and electrometallurgy since 1934 and held the committee chairmanship for 1940–41. He was a member of the Electrochemical Society.

Harold Leonard Smith (M '36, F '42) chief engineer, the Louis Allis Company, Milwaukee, Wis., died April 7, 1944. Born in Niles, Mich., October 16, 1890, Mr. Smith received from Michigan State College the degree of bachelor of science in 1914 and the degree of electrical engineer in 1920. As a graduate student he studied under Benjamin J. Lamme at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., in 1914. Named design engineer in 1915, he entered the United States Navy in 1918 and in 1919 returned to the Westinghouse Company to work on induction motor design. He joined the Howell (Mich.) Electric Motors Company in 1920 as resident engineer and in 1921 joined the Mechanical Appliance Company, Milwaukee, which later became the Louis Allis Company. Within a year he was given the title of chief engineer. Mr. Smith served on many committees of the National Electrical Manufacturers Association and was a member of the Engineers Society of Milwaukee. A number of patents were issued to him.

William deYoung Kay (A '16) treasurer, Lane Cotton Mill Company, New Orleans, La., died January 31, 1944. Mr. Kay, who was born in Memphis, Tenn., November 24, 1891, was graduated from Massachusetts Institute of Technology in 1913. From 1913 to 1919 he was employed by the Edison Electric Illuminating Company of Brooklyn (N. Y.) as salesman and power engineer. After a short association with the Franklin Baker Company, New York, N. Y., he became president of the United Vegetable Oil Refinery, Inc., New York, in 1920. He was partner and president of Kay and Ellinger, New York, from 1924 to 1926, dissolving this partnership to become vice-president of Nathan Straus and Sons, Inc., New York. Employed as a broker and member of the New York Stock Exchange from 1928 to 1936, he also was associated with Halle and Steiglitz, New York, from 1929 to 1931. He was partner in Kay, Byfield and Company, New York, from 1936 to 1943. In 1943 he joined the Lane Cotton Mill Company as treasurer.

Chester M. Davis (A '43) general results engineer, traffic department, Postal Telegraph Cable Company, New York, N. Y., died April 27, 1944. He was born February 28, 1907, in Youngsville, Pa., and was graduated from the University of Pennsylvania with the degree of bachelor of science in electrical engineering in 1929. In 1930 he joined the Postal Telegraph Company, Dallas, Tex., as instructor in testing and regulating. He was made testing and regulating inspector for the company's Southwestern division in 1932 and division traffic superintendent in 1936. He was transferred to New York as general results engineer in 1938. Mr. Davis was a member of Eta Kappa Nu and Sigma Tau.

Edwin Bailey Lovewell (M '43) electrical research engineer, New Britain (Conn.) Machine Company, died in November 1943. Born January 17, 1904, in Royalston, Mass., Mr. Lovewell was graduated from Worcester Polytechnic Institute in 1926 with the degree of bachelor of science in electrical engineering. He entered the employ of the General Electric Company, Schenectady, N. Y., in 1926 as a testman and in 1928 was made industrial control design engineer. From 1929 to 1930 he was stationed in the industrial engineering department where he worked on industrial applications. In 1930 he was transferred to the company's Providence, R. I., office. He was engaged in design and application engineering for Sumner L. Willson, Hartford, Conn., from 1933 to 1942. In 1942 he joined the New Britain Machine Company. He was a member of Tau Beta Pi.

William James Sanford (A '23) commercial salesman, Florida Power and Light Company, Miami, died December 23, 1943. Born August 24, 1878, in Plymouth, Pa., Mr. Sanford commenced his career as general foreman for the Jandus Electric Company, Cleveland, Ohio, from 1899 to 1902. In 1902 he became superintendent for the Camaguey (Cuba) Electric Company. He returned to the United States and served as general manager of the Bellows Falls (Vt.) and Saxtons River Street Railway Company from 1906 to 1920. After a short period as division manager and construction engineer for the Camaguey Company from 1920 to 1924, he joined the Florida Power and Light Company as engineer in the distribution department. In 1942 he was designated commercial salesman.

C. Edward Cole (A '27) staff supervisor, long lines traffic department, American Telephone and Telegraph Company, New York, N. Y., died March 19, 1944. He was born March 2, 1884, in Wilcox, Pa., and was graduated from Stevens Institute of Technology in 1906. After holding various positions with American Telephone and Telegraph Company from 1906 to 1909, he became vice-president and chief engineer of the L. J. Wing Manufacturing Company, New York, from 1910 to 1912. He returned to the American Telephone Company in 1912 as division supervisor in the traffic department and remained in that position until 1924, serving in Atlanta, Ga., from 1916 to 1920. In 1924 he was appointed engineer in the long lines department and staff supervisor in 1940.

Lester L. Conrad (A '36, M '41) supervisor, standards laboratory, Southern California Edison Company, Ltd., Alhambra, died April 6, 1944. He was born October 26, 1888, in Pasadena, Calif., and entered the electrical field in 1910 as electrician for the Fisher Amusement Company. From 1911 to 1917 he was chief electrician for the Clunes Theaters Company and in 1917 entered the employ of the Southern California Edison Company, working on distribution until 1919. Since 1919 he had been supervisor in the standards laboratory. He was a past chairman of the meter committee of the Pacific Coast Electrical Association.

Daniel L. Humm (A '41) New York, N. Y., died in the crash of a United States Navy plane, April 10, 1944. He was born January 14, 1910, in Earlville, Ill., and received the degree of bachelor of science in electrical engineering from the University of Illinois in 1934. He was employed as testing engineer by the McIntosh Electrical Corporation, Chicago, Ill., from 1935 to 1937 and in 1937 joined the Illinois Testing Laboratories, Inc., Chicago, as sales engineer.

Leslie S. Carpenter (A '20) engineer, Chenango and Unadilla Telephone Corporation, Norwich, N. Y., died April 20, 1944. He was born October 27, 1879, in Fletcher, Vt., and attended the University of Vermont. He entered the employ of the New York Telephone Company in 1910 and was named assistant engineer in 1922. From 1927 to 1943 he was associated with the New Jersey Bell Telephone Company as electrical engineer and in 1943 joined the Chenango and Unadilla Telephone Corporation.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on June 15, 1944, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Clingerman, B. H., chief elec. engr., Northern States Power Co., Minneapolis, Minn.
Codding, H. W., asst. engr., Public Service Elec. & Gas Co., Newark, N. J.
Corney, C. A., asst. vice-president and supt. of engg., Boston Edison Co., Boston, Mass.
Forbes, H. C., asst. vice-president, Consolidated Edison Co. of N. Y., Inc., New York
Haines, T. H., asst. vice-president of engg., Boston Edison Co., Boston, Mass.
Hejda, C. J., chief testing engr., Commonwealth Edison Co., Chicago, Ill.
St. Clair, H. P., system planning engr., American Gas & Electric Service Corp., New York
Thomas, R. L., vice-president, Consolidated Gas Elec. Lt. & Pwr. Co., Baltimore, Md.

8 to grade of Fellow

To Grade of Member

Albach, C. R., asst. engr., U. S. Engineer Office, Buffalo, N. Y.
Baker, E. F., elec. engr., Packard Motor Car Co., Detroit, Mich.
Bechlund, O. A., associate engr., Univ. of California, San Diego, Calif.
Berman, Samuel, associate director, Waugh Labs., New York
Beyette, C. K., elec. engr., Texas Electric Service Co., Fort Worth, Texas
Breslauer, N. P., research engr., Allen Bradley Co., Milwaukee, Wis.
Brown, R. P., equipment engr., Southwestern Bell Tel. Co., Dallas, Texas
Burley, J. G., district engr., Bell Tel. Co. of Canada, Toronto, Ont.
Carson, R. B., asst. managing engr., Canadian General Elec. Co., Toronto, Ont.
Coxe, E. H., elec. engr., Aluminum Co. of America, Alcoa, Tenn.
Cross, F. C., application engr., General Elec. Co., Kansas City, Mo.
Culver, D. N., transmission engr., Bell Tel. Co. of Canada, Toronto, Ont.
Ding, A. P., engr., U. S. Engineers, Portland, Ore.
Everest, F. A., engr., Univ. of California, San Diego, Calif.
Gray, W. F., associate prof. of elec. engg., Texas Technological College, Lubbock, Texas
Haanen, N. J., sales engr., Moloney Elec. Co., Chicago, Ill.
Hearson, L. T., engr., American Tel. & Tel. Co., Chicago, Ill.
Heath, E. A., asst. engr., Kansas Gas & Elec. Co., Wichita, Kansas
Hendrickson, E. R., division operating supt., Public Service Co. of Illinois, Glencoe, Ill.
Holt, C. B., asst. prof. of elec. engg., Pennsylvania State College, State College, Pa.
Johnson, A. A., Central Station engr., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.
Jones, H. L., associate prof. of elec. engg., University of New Mexico, Albuquerque, N. M.
Leffell, W. O., instructor in elec. engg., University of Tennessee, Knoxville, Tenn.
Lerstrup, K., elec. engr., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Mencher, I., elec. engr., Emerson-Garden Elec. Co., Elizabeth, N. J.
Nudd, P., asst. prof. in elec. engg., Cooper Union, New York
Rice, I. S., asst. engr. of maintenance, Commonwealth Edison Co., Chicago, Ill.
Ringland, W. L., elec. engg., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Robbins, G. F., supervising engr., Cutler-Hammer, Inc., Milwaukee, Wis.
Rogers, E. W., overhead lines engr., Dallas Power & Light Co., Dallas, Texas
Roach, J. M., engr., Curtiss Wright Airplane Corp., Robertson, Mo.
Schultz, H. G., senior engr., Commonwealth Edison Co. Chicago, Ill.
Sharpe, J. M., asst. supt. of operation, Shawinigan Water & Power Co., Shawinigan Falls, Que., Can.
Sherry, W. H., elec. engr., Ferguson Elec. Construction Co., Buffalo, N. Y.
Spence, B. G., division elec. engr., Oklahoma Gas & Elec. Co., Enid, Okla.
Steiner, H. C., section leader, General Elec. Co., Schenectady, N. Y.
Strelzoff, J. A., associate prof. of elec. engg., Michigan State College, E. Lansing, Mich.
Volckmann, E., junior maintenance engr., New York City Transit System, New York
Warner, E. S., senior plant draftsman, Commonwealth Edison Co., Chicago, Ill.
Waxelman, C., asst. to elec. engr., Consolidated Gas Elec. Lt. & Pwr. Co., Baltimore, Md.
Watson, J. L., meter tester, Portland General Elec. Co., Portland, Ore.
Wright, F., asst. elec. engr., Underwriters Labs., Inc., New York
42 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objectiong to the election of any of these candidates should so inform the national secretary before July 31, 1944, or September 30, 1944, if the applicant resides outside of the United States or Canada.

To Grade of Member

Bacon, F. E., Bacon Elec. Co., Chilliecothe, Ill.
Carleton, H., David Taylor Model Basin, Carderock, Md.
Colter, G. W., Burge & Stevens, Atlanta, Ga.
Condron, E. U., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Coyle, A. B., Line Material Co., Los Angeles, Calif.
Duguid, J. M., Bell Telephone Labs., New York, N. Y.
Duncan, J. A., Jr., American Tel. & Tel. Co., New York, N. Y.
Fidler, I. (Reelection), N. C. Shipbuilding Co., Wilmington, N. C.
Finlayson, H. M., Shawinigan Water & Pr. Co., Montreal, Que., Can.
Fleshman, B. A. (Reelection), Cities Serv. Ref. Corp., Lake Charles, La.
Freitag, R. A., Willamette Iron & Steel Corp., Portland Ore.
Fulton, W. C., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Ginocchio, J. A. (Reelection), Rust Engineering Co., Front Royal, Va.
Gray, R. W., Mountain States Tel. & Tel. Co., Denver, Colo.
Halbach, E. A. (Reelection), Marquette Univ., Milwaukee, Wis.
Harkness, J. R., General Elec. Co., Schenectady, N. Y.
Hinsberger, J. F., City of Santos Imps. Co. Ltd., Vila Matias, Brazil, S. A.
Holloway W., Major, U. S. Army, Ocean Springs, Miss.
Hutcheson, J. A., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Ingalls, D., Titeflex, Inc., Newark, N. J.
James, L. I. (Reelection), Southern Airways, Inc., Decatur, Ala.
Kelsey, H. D., General Elec. Co., Fort Wayne, Ind.
Kessel, R. L. (Reelection), Ill. Inst. of Tech., Chicago, Ill.
Landy, J. J., Aluminum Ore Co., East St. Louis, Ill.
Malpica, J. M., Nat. Powder Factory, Mex. Govt., Santa Fe, D. F., Mex.
McKay, R. (Reelection), Washington Water Pr. Co., Spokane, Wash.
Page, A. W., Major, Royal Engineers, London, England.
Peeples, P., Georgia Pr. Co., Atlanta, Ga.
Reed, G. L. (Reelection), Pub. Serv. Co. of Northern Ill., Chicago, Ill.
von Herrmann, C. F., Jr., Captain, U. S. Army, Birmingham, Ala.
Wagoner, R. M., Hubbard & Co., Chicago, Ill.
Wright, H. P., B. & O. R.R. Co., Baltimore, Md.
32 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Johnson, J. W., Westinghouse Elec. & Mfg. Co., Boston, Mass.
Lee, W., Raytheon Mfg. Co., Waltham, Mass.
Percival, D. R., Norton Co., Worcester, Mass.
Plummer, C. H., Chicopee Mfg. Corp., Chicopee Falls, Mass.
Topliffe, C. V., Cutler-Hammer, Inc., Boston, Mass.

2. Middle Eastern

Boone, D. R., Westinghouse Elec. & Mfg. Co., Philadelphia, Pa.
Colado, R. E., General Elec. Co., Cincinnati, Ohio
Edge, D. R., Central Electric Coop., Inc., Parkers Landing, Pa.
Happold, H. (Re-election), Edward G. Budd Mfg. Co., Philadelphia, Pa.
Law, G. G., Dayton Pr. & Lt. Co., Dayton, Ohio
Lewis, C. B., General Elec. Co., Erie, Pa.
Mauk, G. S., Apex Elec. & Mfg. Co., Cleveland, Ohio
Myers, O. C., Mennonite Central Comm., Akron, Pa.
Prescott, R. S., Naval Ordnance Lab., Washington, D. C.
Rhodes, W. H., Chesapeake & Potomac Tel. Co., Washington, D. C.
Steinhilber, W. B., Electrical Contractor, Ashland, Pa.
Thorbahn, T. S., American Tel. & Tel. Co., Philadelphia, Pa.
Towne, L., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
Wickey, J. R., Clark Controller Co., Cleveland, Ohio
Woodward, B., General Elec. Co., Erie, Pa.

3. New York City

Castronuovo, A. J., Gibbs & Cox, Inc., Kearny, N. J.
Dear, J. A., Federal Shipbuilding & Drydock Co., Newark, N. J.
Dowdell, E., Sperry Gyroscope Co., Brooklyn, N. Y.
Gully, E. J., Todd Shipyards Corp., Hoboken, N. J.
Hammann, R. T. (Reelection), New York Dock Co., Brooklyn, N. Y.
Kral, A., M. W. Kellogg Co., New York, N. Y.
Marks, J. A., Jersey Central Pr. & Light Co., Allenhurst, N. J.
McSherry, L. K., Smith-Meeker Engr. Co., New York, N. Y.
Moenchell, G. E., College of City of N. Y., New York, N. Y.
Race, C. R., Arma Corp., Brooklyn, N. Y.
Rallis, G., John A. Kiamos, Inc., New York, N. Y.
Safonoff, E. M., Moran, Proctor, Freeman & Mueser, New York, N. Y.
Sands, P. J. (Reelection), U. S. Navy Yard, New York, N. Y.
Scarborough, H. B., Federal Tel. & Radio Labs., New York, N. Y.
Vanora, J. A., M. W. Kellogg Co., New York, N. Y.
Whelan, R. L. J., New York Technical Institute, New York, N. Y.
Young, B. B., Lawrance Aeronautical Corp., Elizabeth, N. J.

4. Southern

Bell, T. J., Carolina Pr. & Lt. Co., Raleigh, N. C.
Brady, D. E., Jr., Carolina Alum. Co., Badin, N. C.
Collins, M. M., General Elec. Co., Birmingham, Ala.
Gallant, W. M. (Reelection), Westinghouse Elec. & Mfg. Co., Raleigh, N. C.
Hicks, E. B., Carolina Pr. & Lt. Co., Raleigh, N. C.
Meador, J. T., Southern Elec. Serv., Charlotte, N. C.
Richardson, J. M., Girdler Corp., Louisville, Ky.
Settoon, L. L. (Reelection), East Louisiana State Hospital, Jackson, La.
Smith, E. J., U. S. War Dept., Atlanta, Ga.
Stockwell, H. L., Turner Elec. Works, Jacksonville, Fla.
Travis, J. W., Southern Bell Tel. & Tel. Co., Knoxville, Tenn.
Trout, F. I., Tupelo Water & Light Dept., Tupelo, Miss.
Wellborn, J. M. (Reelection), Rotary Lift Co., Memphis, Tenn.
Westbrook, W. L., Georgia Pr. Co., Columbus, Ga.
Wilson, J. C., Jr., Board of Pub. Util., Athens, Tenn.
Woodd, G. B., Sr., U. S. Naval Operating Base, Key West, Fla.

5. Great Lakes

Bratu, N., Bodine Elec. Co., Chicago, Ill.
Dorsey, J. M., Univ. of Chicago, Chicago, Ill.
Gallatin, P. M., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Grant, G., III, Dow Chemical Co., Midland, Mich.
Greenspon, W., Detroit Pub. Lighting Comm., Detroit, Mich.
Herman, C. J., General Elec. Co., Fort Wayne, Ind.
King, J. J., General Elec. Co., Jackson, Mich.
Kiehn, R. A., Commonwealth Edison Co., Chicago, Ill.
Kolderman, R. W., Dow Corning Corp., Midland, Mich.
Nejedlo, D., Allen-Bradley Co., Milwaukee, Wis.
Schaffen, R. M. (Reelection), Northern Ind. Pub. Serv. Co., Hammond, Ind.
Splees, H. A., General Elec. Co., Fort Wayne, Ind.

7. South West

Benjamin, K. U., Beech Aircraft Corp., Wichita, Kans.
Bruemer, H. H., Jr., Moloney Elec. Co., St. Louis, Mo.
Combs, G. U., Socony Vacuum Oil Co., Augusta, Kans.
Corporon, E. K., Kans. Gas & Elec. Co., Wichita, Kans.
Crafton, W. L., Arkansas-Missouri Pr. Corp., Blytheville, Ark.
Garrison, C. A., Cessna Air Craft Co., Wichita, Kans.
Granich, G. F., Moloney Elec. Co., St. Louis, Mo.
Haun, J. C., International Min. & Chem. Corp., Austin, Texas
Irving, W. S., General Elec. Co., Wichita, Kans.
Johnson, C. V., Beech Aircraft Corp., Wichita, Kans.
Longstaff, R., Kans. Gas & Electric Co., Wichita, Kans.
Lucy, C. C., Radio Station KANS, Wichita, Kans.
Martin, R. H., Boeing Aircraft Co., Wichita, Kans.
Miner, J. T., U.S.N.R., Corpus Christi, Texas
Moore, R. E., Kans. Gas & Elec. Co., Independence, Kans.
Norris, J. M., Kans. Gas & Elec. Co., Wichita, Kans.
Patton, W. S., James R. Kearney Corp., St. Louis, Mo.
Rosenthal, J., Humble Pipe Line Co., Houston, Texas
See, P. G., Consolidated Vultee Air Corp., Fort Worth, Texas

8. Pacific

Aiken, W. R., Permanente Metals Corp., Richmond, Calif.
Binnings, G. F., Marinship Corp., Sausalito, Calif.
Flenner, A. C., U. S. Navy Yard, Mare Island, Calif.
Inman, B. D., Sr., Westinghouse Elec. & Mfg. Co., San Francisco, Calif.
Jenkins, I. G., Jr., Central Arizona Lt. & Pr. Co., Phoenix, Ariz.
Kerber, D. L., Univ. of Calif., Berkeley, Calif.
Maxwell, L. G., U. S. Navy, San Francisco, Calif.
Niemoeller, E. (Reelection), Southern Calif. Tel. Co., Los Angeles, Calif.
Otis, F. H., San Diego Gas & Elec. Co., San Diego, Calif.
Redmond, J. E., J. E. Redmond Co., Phoenix, Ariz.
Ryer, L. M., Kaiser Co., Oakland, Calif.
Sunderland, R. C., Consolidated Vultee Aircraft, San Diego, Calif.
Younger, F. W., U. S. Navy Yard, Mare Island, Calif.

9. North West

Condit, J. M., Associated Shipbuilders, Seattle, Wash.
Doull, A. G., Mountain States Tel. & Tel. Co., Great Falls, Mont.
Eminger, W. D., Montana Pr. Co., Great Falls, Mont.
Hansen, M. O., Montana Pr. Co., Great Falls, Mont.
Johnson, D. A., Mountain States Tel. & Tel. Co., Great Falls, Mont.
Klockler, W. C., Montana Pr. Co., Great Falls, Mont.
Kraft, W. R., Bonneville Pr. Adm., Portland, Oreg.
Mangan, J. J., Bonneville Pr. Adm., Eugene, Oreg.
Reid, R. A., Montana Power Co., Great Falls, Mont.
Richardson, W. D., Montana Pr. Co., Great Falls, Mont.
Staff, C. H., U. S. Army Engrs., Seattle, Wash.

10. Canada

Barbour, C. A., D. M. Fraser, Ltd., Montreal, Que., Can.
Edwards, F. C. N., Northern Elec. Co. Ltd., Regina, Sask., Can.
Eull, L. F., Lieut., R.C.N., Halifax, N. S., Can.
Finch, G. H., Canadian Westinghouse Co., Ltd., Ottawa, Ont., Can.
Mather, R. H. (Reelection), Shawinigan Water & Pr. Co., Montreal, Que., Can.
Streeter E. R. (Reelection), Sorg Pulp Co., Ltd., Port Mellon, B. C., Can.

Elsewhere

Boutacoff, A. A., Mount Isa Mines Ltd., Mount Isa, Aust.
Heeley, F. S., R.A.F., London, England
Jones, E., English Elec. Co., Bradford, England
Race, A. B., British Thomson-Houston Co. Ltd., Manchester, England
Salama, G., Western Gharbia Pumping Stations, El Buscili, Rosetta Line, Egypt

Total to grade of Associate
United States and Canada 114
Elsewhere 5

OF CURRENT INTEREST

Performance of New Walkie-Talkie in Anzio Action Praised

In its baptism of fire in the Anzio beachhead assault the latest Signal Corps "walkie-talkie" or SCR 300 radio set met and exceeded every expectation for range and reliability and was lauded as the most valuable item of radio equipment in the attacking division by the division signal officer.

The SCR 300 set, omnipresent at the Anzio landing, was used in all radio nets from division to infantry companies as well as in Cub observation planes and afterwards was termed the most successful instrument yet devised for amphibious communications. Its range is triple that of the former "walkie-talkie," and it has remarkable clarity of tone attained through frequency modulation which eliminates static. Netting of the sets on one frequency is facilitated by the substitution of the superheterodyne for the super-regenerative receiver. An extra goose-neck-type antenna supplements the standard vertical antenna of such sets. This permits transmission even when the operator is prone on the ground. A headset for the operator and a handset for the officer in command accompany the new model. Miniature radio tubes prolong the life of its batteries and add to its compactness. The set is treated to withstand rain and immersion in water for short periods. Although the new model weighs 35 pounds, as did the older one, its portability is enhanced by an extra strap which encircles the soldier's waist and distributes the set's weight more evenly.

First Telephone Sets Since 1942 Ready for September Production

Resumption of the manufacture of civilian telephone sets which ceased completely in 1942 has been authorized by the War Production Board. Priority in obtaining the annual output of 800,000 sets will be given by the communications division of the Office of War Utilities to the regions most urgently in need of them.

The restriction on the manufacture of the sets was lifted as a war measure to supply essential users, and no general distribution to private persons will be made until all essential needs have been filled. Delivery of the first sets, expected to occur in the late fall, probably will be assigned to the Pacific Coast area where the great industrial expansion caused by the war has been handicapped by a dearth of telephone facilities.

To meet its quota of 80 per cent of the released orders, the Western Electric Company has leased for three years an eight-story plant in St. Paul, Minn., formerly devoted to the manufacture of sporting goods. The plant will be equipped by reinstallation of dismantled machinery from the company's Hawthorne plant, Chicago, Ill., which in common with the company's other plants at present is in full operation fulfilling Government contracts. The company pointed out that this expansion of its facilities will not necessitate any new construction. Production is scheduled to begin in September 1944 with a working force of 1500. Availability of labor supply was a factor in leasing the property in St. Paul.

POSTWAR • • • • •

Postwar Horizons for Plastics Sighted by Scientists

A civilian's preview of four new plastic materials, now employed almost exclusively in military and naval equipment, but expected to compete with steel, wood, and other prime materials in the postwar economy, was conducted recently in New York, N. Y., by the Westinghouse Electric and Manufacturing Company. At the luncheon held in conjunction with the demonstration of Fostorite, Micarta 444, preformed plastic, and a synthetic insulating resin, the men most closely associated with the development of each described the events behind that development.

J. A. Hutcheson, associate director of the Westinghouse Research Laboratories, focused attention on the scientist's and engineer's view of research in plastics. Their viewpoint is directed toward producing a material which can perform a function better than any other material in existence rather than toward producing a mere substitute or ersatz material, according to Doctor Hutcheson. He explained his company's preeminence in the plastics field as a logical outgrowth of its manufacture of electrical products. The company needed, he stated, an electrical insulating material with good structural properties. Though the original impetus to the recent advances in plastics came from wartime scarcities and problems, he forecast that even when a more normal flow of raw materials is restored plastics would compete with the older materials on a strictly utilitarian basis. Their decorative qualities or novelty will not be the primary reason for any postwar expansion, he asserted.

Fostorite, an entirely new impregnating material, and a synthetic resin which substitutes for shellac—both fostered by war needs—were described by C. F. Hill (F '39) manager of the Westinghouse Company insulation department. Developed as an impregnant for standard electrical equipment, Fostorite has solved the problem of effectively moisture-proofing radio, radar, and other communication equipment in the excessively humid atmospheres of tropical climates. Usable without a solvent, Fostorite effects a 100 per cent filling of all space within the insulation. During the impregnation of the coil or device, the impregnant is in a liquid state, but the solvent reacts with another resin dissolved in it, and the whole mass turns to a durable solid. There are no by-products to the reaction that must escape. Though Doctor Hill was unable, for military reasons, to reveal the chemical composition of Fostorite, he mentioned the facts that the complete filling allows much higher-voltage gradients which in turn permits a radical reduction in size and weight of equipment so protected. Moreover the elimination of voids in coils increases the heat conductivity of the structure. Experiments show that it is insoluble in transformer oil as well as water resistant as a coating.

In describing the new synthetic resin Doctor Hill declared that this substitute developed to replace the shellac supply cut off by the war in India ultimately will prove superior to the original material. The tensile strength of fiber-glass bonded with the synthetic resin exceeds that of cast iron or sheet brass and equals that of many steels. The resin appears to be an improvement over natural shellac with its many impurities for use in commutators and electrical insulation, he said. It now promises to eliminate not only shellac but also mica, its companion material in commutators.

The preformed plastic, which is the latest answer to the question of how to combine the great strength of laminated plastics and the more complex shapings hitherto possible only in brittle plastics, was introduced by A. A. Bates. As Doctor Bates defined the problem, the researchers set out to embody the ductility as well as the strength of metals in a single plastic substance. The resulting preformed plastic first materializes as a mixture of wood pulp, water, and a phenolic resin. This is strained by a suction device against a copper-gauze shape of the finished product. The thickness of the end product is controlled by the length of the suction process collecting the fibrous mass around the copper-gauze shape. This preformed plastic piece finally is molded by heat and pressure as any other plastic. The new plastic has been employed successfully in airplane tail fillets and experimentally for airplane propeller hubs.

The story of another war-born technique for stretching the hot plastic material known as Micarta, which is the leading plastic now used for industrial application, was related by E. R. Perry, manager of the Westinghouse Micarta department. Since the war, the new process has enabled the fabrication of complicated shapes from this laminated plastic formerly economically applicable only to shapes derived from such forms as plate, rod, tubes, angles, and channels. War production called for the fashioning of intricate shapes with a minimum of tool steel. Although laminated phenolic was believed for many years to be inert at temperatures below decomposition, recent experiments revealed a stage (at 275 degrees Fahrenheit) of considerable flexibility. When Micarta so treated was cooled to normal temperatures, its average physical properties were recovered. As a result wing-gun ammunition feeds, bomb racks, fuselage tail-wheel housings and aviators' chart cases are being manufactured from the new Micarta 444. Doctor Perry reported that a one-inch bar of the material will stand a tensile pull of 13,000 pounds and can carry a compression load of 30,000 pounds without cracking. At

temperatures as high as 170 degrees Fahrenheit, it will not wilt and even gains in impact strength. This strong lightweight decorative material is expected to influence the fields of furniture, lighter railroad car, and automobile manufacturing after the war.

Proposed Postwar Unemployment Compensation Plan

A plan for withholding a percentage of present war-production profits for the postwar benefit of returning veterans and unemployed war workers was outlined recently by Willard F. Rockwell, chairman of the board, Timken-Detroit Axle Company and Standard Steel Spring Company. Presented as a contribution to postwar planning, it is designed to promote a measure of security for both labor and industry in the economic upheaval that will follow contract terminations.

The six basic points of the "Rockwell plan" are:

"1. Every company engaged in whole or substantial part with war production be permitted to withhold from 1943–44 and 1945 gross income, after taxes and normal profit, and before renegotiation, a sum up to the equal of one average week's wage or salary for each month of continuous employment of each person on the payroll, with a maximum total equal to 24 weeks' wage or salary for employees who have worked two years or more.

"2. Based upon the same formula, an equal sum to be withheld for each ex-employee now serving in the Armed Forces, with the same maximum and minimum withholdings operative.

"3. These funds shall be held by each company. A complete record of such withholdings, together with the record of each active employee, plus those serving in the Armed Forces, shall be sent to the Social Security Board. Payments out of the fund shall also be recorded with the Social Security Board. These records shall be available to the public.

"4. Disbursements of these funds to unemployed workers will start at the time of complete cancellation of war contracts. Or in the instance of graduated contract cancellations due to readjustments in the war-production program, a joint labor–management committee in each plant shall determine the mutually satisfactory point at which disbursements shall start. In the case of ex-employees returning from the Armed Forces, payment shall start upon personal application of each ex-employee.

"5. Disbursements are to be made at a rate in conformity with the maximum and minimum established by state or Federal governments for unemployment compensation, until

(*a*). A job of comparable skill and compensation as last held shall be made available to each person entitled to these benefits, or

(*b*). Until such time as the total benefits accruing to each individual employee are completely disbursed, or

(*c*). Until other employment is obtained by each person entitled to these benefits.

"6. At the end of two years after complete settlement of all terminated war contracts, all withheld funds not disbursed by the companies operating under this plan shall be paid to the Federal government."

In addition, the plan includes a recommendation that the Government establish a board of business men to survey the complicated surplus-property and production-facility inventories now under the control of government procurement agencies for the purpose of recommending immediate steps to reduce these surpluses so as not to dislocate the national economy when the war ends.

Colonel Rockwell, who is also chairman of the board and president of the Pittsburgh Equitable Meter Company and chairman of the boards of the Hupp Motor Company and the Merco-Nordstrum Valve Company, has petitioned President Roosevelt and Congress for permission to institute this postwar plan in his own companies.

CED Publishes First Study on Postwar Economy Problems

The research program of the Committee for Economic Development, which represents a comprehensive study on postwar economy problems by businessmen and economic experts, recently published its first survey, "Production, Jobs, and Taxes," by Harold M. Groves, professor at the University of Wisconsin. The book is a survey of the federal tax structure, with recommendations for a postwar tax program that will be conducive to high levels of peacetime production and employment. It is the first of some 20 research studies now under way or projected by the research committee of CED.

Included in the subjects being studied are:

Liquidating war production.
Removing wartime economic controls.
Financing the reconversion and expansion of business.
Man-power demobilization and re-employment.
Providing for transition unemployment.
Money and banking policy during the transition.
Agriculture after the war.
International economic relations in the postwar world.

Chairman of the research committee of businessmen is Ralph E. Flanders, president of the Jones and Lamson Machine Company. Chairman of the research advisory board of social scientists is Professor Sumner H. Slichter of Harvard University, Cambridge, Mass. Theodore Yntema, professor of economics on leave from the University of Chicago, Ill., is director of the staff of economists.

Rivalry for Postwar Control of World-Wide Communications

The United States Government is planning now to gain a share in control of the world's system of postwar communications, according to a recent article in the *United States News*. International communications in the past have been dominated by Great Britain, and lower rates have been given to British, Canadian, Australian, and other Empire businessmen than are available to people of the United States communicating with persons in the British Empire. The British maintain a flat rate of 30 cents per word for cablegrams and radiotelegrams between any two points in the Empire, whereas rates to residents of the United States in some instances may exceed one dollar per word.

Congress will be asked to shape a new policy for American communications companies, in order that the United States may enter into discussions on matters of rate control and service restrictions.

INDUSTRY.....

Military and Postwar Radio in Russia Discussed by Ellis

Speaking on "Radio in Russia" before the third War Production Conference and the 20th annual membership meeting of the Radio Manufacturers Association in Chicago, Ill., June 6, 1944, Ray C. Ellis, director of the radio and radar division of the War Production Board, described his impressions gained during a six-week intensive study in Russia of Soviet electronic-equipment requirements.

Mr. Ellis visited representative radio factories in Moscow and the Ural region, and observed development trends, types and quantities of products being manufactured, and organization and facilities. Purpose of the visit was to discuss with Soviet engineers and factory managers their military electronic situation in relation to their production and our assistance as well as to discuss plans for closer working arrangements in the radio field both now and after the war.

As compared with the radio industry in the United States, Mr. Ellis found that of Russia prior to the war quite small. Home and apartment installations used loud-speakers each with a volume control which were connected to a centrally operated receiver. Because of small production, hand methods, and lack of suitable transportation, most of the 15 factories producing radio sets made all of their own parts except the tubes and loud-speakers. There was no standardization of parts, and the factories did very little development work themselves because the design and development of new models originated with a central government planning agency.

What research and development was in progress was set up separately from the factories, Mr. Ellis reported, and was associated with the universities at Leningrad and Moscow, and with the National Academy of Sciences in Moscow. The programs consisted mostly of work on high-powered transmitters, television, and special tubes, with little concentration on receiving tubes, short-wave sets, high fidelity, frequency modulation, loud-speakers, or component parts. There were two experimental television stations in operation.

Foreign contact by Russian engineers was kept to a minimum, even before the '30's. That permitted was limited largely to representatives of the Radio Corporation of America, some German assistance in Leningrad on tubes, and some English help on a loud-speaker plant.

When Germany invaded Russia in June 1941, all of the radio industry had to be evacuated, under extremely adverse conditions, from locations in the west to central Siberia, Mr. Ellis explained. Although much of the work after the invasion was conducted under extremes of weather and warfare hazards, many of which still prevail, he found that the factories had all the elements of a modern plant, and that both production and morale were at a high level.

Mr. Ellis reported that entire plants are on a quota basis, with production results posted every ten days. All radio-factory employees are on an incentive basis, with the total weekly pay check dependent upon their rate of production. Workers in departments other than production are awarded medals for outstanding performance, which they proudly wear and which also entitle them to additional food coupons, better seats at the opera, additional gasoline for their cars, and in general provide a basis for a higher standard of living.

For postwar expansion Mr. Ellis declared that the Russians were in possession of the

knowledge and ability to establish plants comparable in operating efficiency to the radio factories in the United States.

Expanded Oil Output Will Aid New Industries in Latin America

Increase in power supply is the fulcrum of industrial progress in Latin America, according to a report from a recent issue of the *United States News*. It will be accomplished largely through the development of hitherto untapped petroleum resources in Brazil, Peru, and Ecuador, and through expansion of petroleum production in Argentina and Venezuela.

Since coal has been found only in small quantities south of the Rio Grande so far, and since hydroelectric expansion, although potentially large, is a long-term program which undoubtedly will necessitate government participation, petroleum offers the immediate answer to the fuel and power problems of new Hemisphere industries. The Peruvians already have started production in the previously untapped trans-Andean region of the Amazon basin, drilling in Brazil and Ecuador has been delayed awaiting equipment held up by the war, and development in Haiti, Santo Domingo, and other countries is still in the exploratory stages.

In the meantime, production in Venezuela, whose proved resources are expected to make her the world's second oil producer, is running at almost 50 per cent above the low of 1943, caused by the shipping shortage. By the end of 1944, Venezuelan production is expected to reach 750,000 to 800,000 barrels daily. This compares with a recent high in the United States of 4,500,000 barrels a day.

One of the most interesting facts about this expansion is the mutual-assistance basis by which it will be achieved. The recent Conference of Inter-American Development Commissions urged the co-operation of the Hemisphere countries in supplying much of the necessary capital, technicians, and machinery, themselves.

Since Venezuela's Central Bank has been unable to sell importers the dollars turned in by United States oil firms to obtain bolivars for their operations, the capital for Venezuelan oil expansion will have to be supplied by national funds. The funds will be negotiated in bolivars borrowed from the Central Bank, or in gold, imported to strengthen Venezuelan reserves and to remove surplus funds from the market. Use of local funds may indicate a new trend of growing national participation in foreign-owned enterprises, and may reduce prevalent high interest rates in Latin America.

Expansion of Argentine petroleum production will influence United States–Argentine trade relationships indirectly, since increased industrialization will lessen reliance on farm exports, largely to Great Britain, to maintain Argentine economy.

High-Frequency Electric Field Used in Processing Foodstuffs

Uhlmann patent 1,992,515 entitled "Apparatus for the Preparation of Foodstuffs," available for licensing through the Alien Property Custodian, describes equipment by which raw food materials are subjected to a high-frequency induced electric field for processing. The apparatus is a wave oven which consists of a transformer coil supplied with 220 volts at 50 cycles, a secondary coil connected to a capacitor, a spark gap, and another coil that emits a high-frequency field of 800 meters or less.

The method may be used to can foodstuffs as well as to cook and preserve them. Advantages claimed are saving of time, improvement in taste, and retention of vitamins and mineral salts. Fruits can be cooked in their skins without loss of shape, and milk is freed of living organisms without heating to 100 degrees centigrade, or boiling temperature. It also may be used to brew coffee and tea, obtaining the same extraction at a maximum temperature of 70–75 degrees centigrade (169 degrees Fahrenheit) as compared with the temperature of 100 degrees centigrade when made by the usual methods.

Many other inventions relating to food processing, machinery, and packaging are included in the 45,000 vested patents and patent applications which have been seized by the Alien Property Custodian from enemy aliens and nationals of occupied countries. Catalogues and class lists of vested patents may be purchased from the Alien Property Custodian, Chicago 3, Ill., or are available for public inspection, along with copies of the patents, in the Custodian's patent administration division offices in Washington, D. C., New York, N. Y., Chicago, Ill., Boston, Mass., and Portland, Oreg. Catalogues may also be consulted in the regional and field offices of the Smaller War Plants Corporation. License applications should be addressed to the Alien Property Custodian, Division of Patent Administration, Washington 25, D. C.

Electronic Sorting Table Speeds Inspection of Contact Assemblies

Much greater speed in the sorting and inspection of tiny contact assemblies produced at General Electric Company, Schenectady, N. Y., has been made possible through the development of an electronic sorting table that routes the assemblies into three different channels, depending on whether they are too high, too low, or within the tolerances.

The specially designed sorting table incorporates a new electronic relay and a factory-constructed "contact head." Each assembly is fed onto a 45-degree slide that is part of the contact head. About halfway down the slide the assembly comes to a contact point located at preset height. If the assembly touches the point, it is oversize, and the contact made closes the grid circuit of the relay's electronic tube, which in turn energizes an electromagnetic relay. A solenoid is energized next, thereby sending the assembly down a chute into a container for oversize parts. A short distance beyond the first point a second contact point is set

Navy LST Boats Steered Electrically

The extreme mobility needed by the Navy's landing stage tank craft for the successful landing of troops, often under enemy fire, is afforded by this electrically operated quadrant steering gear designed and built by the Baldwin Southwark division of the Baldwin Locomotive Works. Located below deck in a compartment just above the rudders in the stern of the craft, the gear is operated electrically by remote control from the wheel on the bridge. In case of power failure the gear can be hand-operated. The quadrant arc in which the gear swings and the long steel arms which transmit the motion of the gear to the rudders are shown here

at standard height less tolerance. Since oversize assemblies have been eliminated already, parts touching the second point are within acceptable limits and are shot down a second chute. Undersize assemblies do not touch either point and slide undisturbed into a third tray.

Previously, the contact assemblies, each almost small enough to require handling with tweezers, were sorted and inspected by hand. Each assembly was checked with a needle micrometer and then sorted accordingly.

Central Bureau Established for Rural Electrification Data

The Rural Electrification Information Exchange, a central bureau for the collection, analysis, and indexing of all information now available on the uses of electricity on farms, has been established by *Farm Journal*, one of the largest rural magazines in the United States.

Much experimental research and engineering work on rural electrification has been done by agricultural schools, electric utilities —private and Rural Electrification Administration companies, manufacturers, and others, but the information has remained in the files of the individual institutions, for the most part. Through the new central agency it will be made available on request to manufacturers, advertising agencies, wholesalers, farm electrical dealers, utilities, all REA agencies and co-operatives, agricultural schools, experimental stations, county agents, the press, and any others interested. This service also will be extended to farmers in an effort to help them meet individual electrification problems.

The Exchange will be under the direction of Frank E. Watts, executive assistant of the *Farm Journal* who has been specializing in the study of farm electrification for the past three years. Contributions from those having such data in their files are being solicited eagerly, and should be addressed to headquarters of the Rural Electrification Information Exchange, c/o *Farm Journal*, 420 Lexington Avenue, New York 17, N. Y.

Emergency Commercial Standard for Dial Indicators Proposed

A Proposed Commercial Standard (Emergency) for Dial Indicators, *TS*-3712, has been developed recently by the National Bureau of Standards to provide minimum essential requirements for precision dial indicators. In its present form the standard has been revised in line with composite critical opinion from the leading users, Government agencies, distributors, and manufacturers to whom it had been sent previously for review and comment. Currently it is being circulated to the trade for written acceptance, in order that it may be established as a commercial standard and be published by the Department of Commerce.

The specification covers the major essential requirements of precision dial indicators in four size groups of nominal bezel diameters, and takes up nomenclature, general requirements, detail requirements, packing, and marking. Included in the standard are four descriptive sketches of the instruments and two tables. Should the number of acceptances received warrant publication, printed copies of the standard may be obtained from the division of trade standards, National Bureau of Standards, Washington 25, D. C.

Westinghouse Purchases West Coast Radio Station. Radio station KEX, a Portland, Oreg., affiliate of the Blue Network transmitting on a frequency of 1,190 kilocycles, has been purchased by Westinghouse Radio Stations, Inc., subject to the approval of the Federal Communications Commission. According to a joint announcement from Westinghouse and from Palmer Hoyt, publisher of the Portland (Oreg.) *Oregonian*, the former owner of the station, the disposition of KEX complies with a recent FCC order limiting ownership by a single operator to one standard broadcast station in a community. Both companies were affected by the order because the *Oregonian* also owns and operates station KGW in Portland, and Westinghouse owns and operates two stations, WGL and WOWO, in Fort Wayne, Ind. Negotiations currently are in progress for the disposal of WGL by Westinghouse. When the Commission's approval has been granted, KEX will be under the general direction of Leo B. Wailes, manager of Westinghouse Radio Stations, Inc. The station has been operating since 1926.

Philco Sets Up Television Relay Transmitter Link. A New York to Philadelphia television relay transmitter link, connecting the two cities for video broadcasts, has been established by Philco Corporation, Philadelphia, Pa., and was officially dedicated on May 25, 1944. The new link, installed near Princeton, N. J., replaces previous experimental installations, and reputedly marks the beginning of the first regularly scheduled television relay system capable of providing commercial service in the United States. It is now in operation every night to make the New York programs of station WNBT available to the audience of Philco television station WPTZ in Philadelphia.

RMA Officers Elected. The Radio Manufacturers Association meeting recently in Chicago, Ill., in its third war production conference elected the following officers for the coming year:

President: R. C. Cosgrove, Cincinnati, Ohio.

Vice-presidents: E. A. Nicholas, Fort Wayne, Ind., D. T. Schultz, Newton, Mass.; Walter Evans, Baltimore, Md.; R. C. Sprague (M '40), North Adams, Mass.; T. A. White, Chicago.

Directors: H. A. Bell, Los Angeles, Calif.; R. E. Carlson, Newark, N. J.; Monte Cohen, Springfield, Mass.; S. I. Cole, New Bedford, Mass.; F. M. Folson, Camden, N. J.; G. R. Fryling, Erie, Pa.; Joseph Gerl, Chicago; F. R. Lack (M '37), New York, N. Y.; George Lewis, New York; Ernest Searing, Philadelphia, Pa.

Addition of 12 new members of RMA also was announced at the Chicago meeting. The new members are:

Consolidated Radio Products Company, Chicago; Crystal Research Laboratories, Inc., Hartford, Conn.; Electronic Laboratories, Inc., Indianapolis, Ind.; Electronic Engineering Company, Chicago; Electronic Tube Corporation, Philadelphia; General Electronics, Inc., New York; Selenium Corporation of America, Los Angeles; M. Simons and Son Company, Inc., New York; Mark Simpson Manufacturing Company, New York; Universal Microphone Company, Inglewood, Calif.; Viewtone Company, New York; Winters and Crampton Corporation, Grandville, Mich.

The Association's engineering department also arranged with the co-operation of the Society of Automotive Engineers for a series of tests of frequency modulation and other receivers on problems of automobile interference with television and FM reception. An appropriation of $5,000 was authorized for the project.

JOINT ACTIVITIES

Subcommittee of ECPD Reports on Technical-Institute Education

The subcommittee on technical institutes of the Engineers' Council for Professional Development recently presented a report for the purpose of clarifying the status and promoting the development of educational programs of the technical-institute type.

The report, which was subsequently submitted to the various engineering societies for their action, describes the scope of technical-institute education and suggests minimum requirements and recommendations as to how they may be effected. The AIEE board of directors, at its meeting on May 25, 1944, passed a resolution approving the plan for accrediting those technical schools recommended by the ECPD subcommittee.

As defined in the report, the purpose of these technical education programs is to prepare individuals possessing a high-school education or the equivalent for positions auxiliary to but not in the field of professional engineering. The work is essentially technological in nature, including virtually the entire range of engineering and technical industrial practice, and the programs verge upon skilled craftsmanship at one end of the scale and approach professional engineering practice at the other. Courses are more intensive and specific in purpose than are the collegiate engineering curricula, and in duration range from a few weeks to two or three years of full-time day-school or five or six years of evening-school attendance.

From a number of independent studies of technical-institute education, the subcommittee ascertained a need in industry for at least three times as many graduates from technical institutes as for those graduating from four-year engineering college courses. Since the output of the technical institutes falls far short of this number and since the needs of industry must be served, many engineering graduates are employed for positions requiring less expensive and less fundamental training than that provided by the degree-conferring college.

Then, too, laws governing the registration of engineers do not recognize technical-institute graduation in evaluating educational qualifications for licensure. Accrediting procedures do not include the technical institutes, and their graduates, therefore, receive no official credit for a

Future Meetings of Other Societies

American Association for the Advancement of Science. Annual meeting, September 11–16, 1944, Cleveland, Ohio.

American Society of Civil Engineers. July 16–21, 1944, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, October 2–5, 1944, Cincinnati, Ohio; annual meeting, November 27–December 1, 1944, New York, N. Y.

Institute of the Aeronautical Sciences. Summer meeting, July 27–28, 1944, Los Angeles, Calif.; air transport meeting, September 1944, Washington, D. C.; fall meeting, November 1944, Dayton, Ohio.

Society of Motion Picture Engineers. 56th semiannual fall conference, October 16–18, 1944, New York, N. Y.

program of study that has prepared them adequately for service in numerous technical positions.

In view of these facts the committee recommended that both industry and the engineering profession act, in their own interests if for no other reason, to place technical institute education on a proper basis of quality and magnitude in the United States. Because of the diversification of programs in the various schools operating in the technical-institute field, it was suggested that each one, within stated boundaries, be judged on its own merits as to quality, and that each should be recognized and accredited in terms of its own purposes, scope, duration, and content. However, since some qualitative limits must be established within which acceptable programs must fall, the following requirements were advanced as a tentative statement of qualifications that all programs must satisfy in order to be considered.

1. Duration: not less than one academic year of full-time work, or the equivalent in part-time work.

2. Requirement for admission: high-school graduation or the equivalent.

3. Curricula: technological in nature, employing the application of physical science and the techniques of mathematics to the solution of practical problems, and comprising a prescribed sequence of related courses with a reasonable amount of elective subject matter.

4. Instruction: by accepted class, laboratory, or correspondence methods.

5. Teaching staff: qualified as to education and experience.

6. Educational institution: an organized school or a division of an institution devoted to the specific aim of education of the technical-institute type; a stable organization with adequate financial support.

7. Physical facilities: adequate for the programs offered.

The subcommittee further recommended that recognition or certification of educational programs of the technical-institute type be initiated by the ECPD, since it is the only agency of the engineering profession which has the status, backing, and public recognition necessary to insure acceptance of such certification. Power should be vested in an accrediting group, which would include representatives of the institutes themselves and of the industries served by them.

Editor's Note: As an alternative to certification by an ECPD board, an accrediting organization may be established by the institutions themselves. The National Council of Technical Schools, organized in January 1944 (see *EE, April '44, p 158* and *July '44, p 278*) is a step in this direction.

EDUCATION • • •

Minimum Standards Adopted by Council of Technical Schools

An amended Code of Minimum Standards recently was adopted by the National Council of Technical Schools. Revision of the tentative code adopted in January 1944 was based on the suggestions of eminent educators, State educational administrators, and personnel directors in industry to whom the code was submitted for comment and criticism.

After fixing the realm of the technical school between that of the trade school which teaches skills and crafts and that of the academic institution which prepares primarily for the scientific and learned professions, the approved code sets up these general qualifications for such schools:

1. Its principal courses of instruction shall be terminal rather than preparatory, intensive, practical, reflecting the best current technical practices of the field it serves.

2. Its principal courses shall either consist of one year of not less than 1,200 clock hours of class and laboratory work or have the approval of a State or Federal agency.

3. Its adequate financial resources must be evident.

4. Its manager and owners must have a satisfactory record of business integrity.

5. It must possess the confidence of the leading employers in the field it serves and maintain a satisfactory record of employment of its graduates.

6. It must be in operation five years before it is eligible for membership in the council. However newer institutions may become nonvoting members.

7. It must comply with Government requirements for its type of school in the State in which it operates.

The code then goes on to present standards for the various grades of faculty members, the educational director, chief classroom instructor, chief laboratory instructor, and other instructors. Details of the regimen of the school—qualifications for admission, content of courses, size of classes, grading system, and building facilities—must satisfy a certain minimum. An ethical guide governing fees, advertisements, recruiting of students, and school representatives also is established by the code.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Wigwags, Zips, and Zooms

To the Editor:

I still read *Electrical Engineering* with care. My six-year-old granddaughter, "Happy," joins me to look at the "wigwags, zips, and zooms." "Happy," whose name is Anne Carolyn Burnett, uses these terms:

"wigwags" = oscillograms
"zips" = rising curves
"zooms" = falling curves
"scooters" = wheeled transformers, or tanks

"Happy" zealously and carefully goes over *Electrical Engineering* as it is received, and her questions demand intelligent answers. I suppose she is your youngest student.

DOUGLASS BURNETT (M '04)
(Retired engineer, Sparks, Md.)

The Engineering Degree

To the Editor:

Almost every time I look at the personal column in any of the engineering magazines, I note a number of engineers listed as having degrees: bachelor of science in . . . engineering, bachelor of engineering in . . . engineering, or bachelor of philosophy in . . . engineering and I often have wondered why steps are not taken to provide a means whereby engineering graduates with bachelor degrees can earn their engineering degrees without resident rematriculation.

Some institutions confer an engineering degree upon the completion of a four-year course while others (probably in the majority) require at least a year of resident graduate study as a requisite for such a degree.

Most engineering graduates find it necessary or expedient to seek employment soon after graduation and hence never find the time or the opportunity to take the additional year's work. The result is that the holders of bachelor's degrees, for the most part, are deprived of the opportunity of possessing engineering degrees no matter how much they may desire them or need the additional learning associated with them.

If the engineering schools cannot consistently confer an engineering degree with the four-year courses as now constituted, perhaps increasing the length of the scholastic year by shortening the vacation periods would permit giving the added work necessary for earning such a degree in the four-year period.

As an alternative proposition, I don't see why the various engineering schools which consider the normal four-year course insufficient for an engineering degree couldn't institute correspondence courses for their graduates, thereby making it possible for the latter to procure the higher degree.

At the present time the officials of many universities and colleges are wondering where they are going to find enough students to keep their respective institutions in the going concern class—at least for the duration and perhaps for sometime after. If they cannot find students for the undergraduate

courses, I believe they have an opportunity, if they are so disposed, to keep their teaching staffs at least partially employed through the instrumentality of graduate correspondence courses.

I would be ready and willing to try such a plan even though my bachelor's degree is 37 years old.

It would be interesting to know what other "bachelor engineers" think of the graduate correspondence course.

HAROLD M. GOULD (M '42)

(Industrial engineer, Smith, Hinchman, and Grylls, Inc., Architects and Engineers, Lake City Ordnance Plant, Lake City, Mo.)

NEW BOOKS • • •

The following new books are among those recently received from the publishers. Books designated ESL are available at the Engineering Societies Library; these and thousands of other technical books may be borrowed from the library by mail by AIEE members. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books. All inquiries relating to the purchase of any book reviewed in these columns should be addressed to the publisher of the book in question.

Tool Steels. By J. P. Gill, R. S. Rose, G. A. Roberts, H. G. Johnstin, and R. B. George. American Society for Metals, Cleveland, Ohio, 1944. 577 pages, illustrated, 9¼ by 6 inches, cloth, $6. (ESL.)

The aim in this book is to set forth concisely the existing theoretical and practical information on the types of tool steel that commonly are used. A description of the manufacture of tool steel is followed by chapters on testing, the principles of heat treatment, and the effect of alloying elements on the steel. Succeeding chapters review in detail the various classes of tool steels, presenting the available data about their properties, treatment, and uses.

Oxy Acetylene Handbook. Published by Linde Air Products Company, New York 17, N. Y., 1943. 587 pages, illustrated, 9½ by 6 inches, cloth, $1.50. (ESL.)

This is a practical basic manual intended for use in colleges, vocational schools, and shop training courses. All topics from general principles to inspection of welds and the management of shops are covered. The book supersedes the "Oxwelder's Handbook."

Modern Turbines. By L. E. Newman, A. Keller, J. M. Lyons, L. B. Wales. Edited by L. E. Newman. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 175 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. (ESL.)

Information concerning the characteristics of steam turbines and their generators is presented for the use of engineers who are interested in the selection of equipment for a given job, but are not concerned with the details of turbine design and maintenance. The material presented appeared originally in *Power Plant Engineering*.

Theory of the Gyroscopic Compass and Its Deviations. By A. L. Rawlings. Second edition completely revised and reset. Macmillan Company, New York, N. Y., 1944. 182 pages, illustrated, 8½ by 5½ inches, cloth, $3. (ESL.)

The theory of this compass is presented by an authority who has invented various important improvements. Included are descriptions of the Sperry, Anschütz, Arma, and other models in use today. Navigators and men concerned with the installation and maintenance of gyrocompasses, and advanced instructors in schools will find the book useful.

ASTM Standards 1943 Supplement Including Tentative Standards. Part I, Metals. 351 pages. Part II, Nonmetallic Materials—Constructional. 167 pages. Part III, Nonmetallic Materials—General. 539 pages. American Society for Testing Materials, 260 South Broad Street, Philadelphia 2, Pa., 1944. Illustrated, 9¼ by 6 inches, cloth, $3 each part. (ESL.)

These volumes bring the 1942 book of standards up to date by giving the newly adopted and revised standards and tentative standards. Included are stickers for marking the superseded standards in the 1942 books.

ASTM Standards on Rubber Products. Prepared by ASTM committee *D*-11 on rubber products; methods of testing, specifications, February 1944. American Society for Testing Materials, 260 South Broad Street, Philadelphia 2, Pa., 424 pages, illustrated, 9 by 6 inches, paper, $1.75. (ESL.)

This compilation brings together the standard and tentative methods of test and specifications pertaining to rubber products. Additions in this issue include specifications for compounds of rubber and synthetic rubber for automotive and aeronautical uses and for electric wire and cable insulation; methods of testing rubber-coated fabrics, asbestos sheet packing, and nonrigid plastics; and electrical test methods applicable to rubber products.

Alternating Current Bridge Methods. By B. Hague. Fifth edition. Sir Isaac Pitman and Sons, London, England; Pitman Publishing Corporation, New York, N. Y., 1943. 616 pages, illustrated, 9 by 5½ inches, cloth, $8.50. (ESL.)

The purpose of this book, is to provide advanced students with an up-to-date account of methods and apparatus for a-c bridge measurements of inductance, capacitance, and effective resistance at low and telephonic frequencies. The symbolic theory of alternating currents and its application to bridge networks, the principle underlying the various instruments involved, the classification of bridge networks, and the choice of methods are discussed at length. Because of war limitations, the text is that of the fourth edition, but errors have been corrected and many notes covering later developments added. Bibliographic footnotes are frequent.

Chemistry of Cellulose. By E. Heuser. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 660 pages, illustrated, 8½ by 5½ inches, cloth, $7.50. (ESL.)

This book provides a compendium and critical digest of the literature on cellulose, with due consideration of the microscopic and submicroscopic structure of the cellulose fiber. The scientific aspect rather than the practical application of cellulose chemistry has been emphasized. An attempt has been made to consider all the essential literature up to October 1943.

Engineering Materials, two volumes. Volume 1—The Ferrous Metals. 369 pages, $7.50 (25*s.* abroad). Volume 2—Nonferrous and Organic Materials. 479 pages, $8.50 (30*s.* abroad). By A. W. Judge. Second edition. Pitman Publishing Corporation, New York 19, N. Y.; Sir Isaac Pitman and Sons, London, England, 1943. Illustrated 9 by 5½ inches, cloth. (ESL.)

These two volumes form an admirable reference book for engineers, designers, constructors, and others concerned with the selection and application of engineering materials. Volume 1, on ferrous metals, presents essential information on their properties, composition, heat treatments, machining, welding, and other subjects. Volume 2, treats in similar fashion the nonferrous metals and alloys, plastics, rubber, and ceramics. The needs of aircraft and automobile engineers especially have been kept in mind.

Ferrous Metallurgy, two volumes. Volume 1—Introduction to Ferrous Metallurgy. 484 pages. Volume 2—Manufacture and Fabrication of Steel. 487 pages. By E. J. Teichert. Second edition. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. Illustrated, 8½ by 5¼ inches, cloth, $4 each. (ESL.)

The two books are part of a three-volume text based upon a correspondence course given during recent years by Pennsylvania State College. Volume 1 covers the fundamental chemical and physical background and the manufacture of pig iron, cast iron, and wrought iron; volume 2, the manufacture of steel and its primary fabrication. The books give an excellent up-to-date account of practice.

General College Chemistry. By M. C. Sneed and J. L. Maynard. D. Van Nostrand Company, Inc., New York, N. Y., 1944. 861 pages, illustrated, 8½ by 5½ inches, cloth, $3.75. (ESL.)

This text is designed for a first-year course in college chemistry in which theory and descriptive matter are balanced carefully. Historical material is introduced, and statistical and industrial materials are used freely. The work aims to give the student the necessary preliminary information for a well-rounded training in chemistry.

Graphical Solutions. By C. O. Mackey. Second edition. John Wiley and Sons, Inc., New York, N. Y.; Chapman and Hall, London, England, 1944. 152 pages, illustrated, 8½ by 5½ inches, cloth, $2.50. (ESL.)

Further demand has made necessary the reprinting of this edition which appeared first in 1940. It provides a course of instruction in the construction and application of curves, diagrams, and charts for the graphical and mechanical solution of engineering problems. The treatment is elementary and practical.

Handbook of Chemistry. Compiled and edited by N. A. Lange. Fifth edition. Handbook Publishers, Sandusky, Ohio, 1944. 2,092 pages, with an appendix of mathematical tables and formulas compiled by R. S. Burington. Illustrated, 8 by 5½ inches, fabrikoid, $6. (ESL.)

The fact that five editions of this handbook have been printed in ten years shows that it has met a demand for a convenient collection of basic data on chemistry. The new edition has been revised throughout, many tables have been extended or rewritten, and new tables have been added on flammable liquids, flame temperatures, plastics, fluorescent substances, and water for industrial use.

Illustrated Technical Dictionary. Edited by M. Newmark. Philosophical Library, 15 East 40th Street, New York, N. Y., 1944. 352 pages, illustrated, 9¼ by 6 inches, cloth, $5. (ESL.)

This dictionary defines a wide selection of terms, including many recent expressions, used in the applied sciences and in technology. Special attention is given to those generally encountered in the curricula of technical and vocational schools. Illustrations are infrequent and add little to the value of the book. The work will be useful to students and mechanics.

Industrial Electronic Control. By W. D. Cockrell. McGraw-Hill Book Company, Inc., New York N. Y., and London, England, 1944. 247 pages, illustrated, 8¼ by 5½ inches, cloth, $2.50. (ESL.)

The purpose of this book is to supply a basic working knowledge of electronic control as a background for intelligent selling, installing, or servicing of electronic equipment. It describes, simply and nonmathematically, the fundamentals of electronic-tube operation and the basic control circuits. The book is especially for electrical engineers with no previous experience with tubes, and radio servicemen interested in electronic service work.

Iron and Steel in Britain 1870–1930. By T. H. Burnham and G. O. Hoskins. George Allen and Unwin, London, England; distributed by W. W. Norton and Company, Inc., New York, N. Y., 1943. 352 pages, illustrated, 8½ by 5½ inches, cloth, $7.50. (ESL.)

In 1870 the British iron and steel industry held first place in the world. In 1930 it ranked fourth, both in production and exports. This volume studies the history of the industry during the interim in order to discover the factors responsible for this decline in position, and endeavors to appraise the part played by each. The book is an interesting carefully documented study. One author is a metallurgist, the other an economist.

Klystron Technical Manual. Published by the Sperry Gyroscope Company, Brooklyn 1, N. Y., 1944. 94 pages, illustrated, 9¼ by 6 inches, cloth, limited free circulation. (ESL.)

This manual describes the underlying principles of velocity-modulation tubes, rather than their applications. It brings together in simplified form the material hitherto available only in periodicals with additional experimental and descriptive information. A useful bibliography and lists of American and British patents are included.

Materials and Processes. Edited by J. F. Young. John Wiley and Sons, Inc., New York, N. Y., 1944. 628 pages, illustrated, 8½ by 5½ inches, cloth, $5. (ESL.)

This book aims to present a broad study of the materials and manufacturing processes employed by engineering designers and thus to provide information directly useful in the selection of materials. It is intended for classroom use as well as for engineers who wish an over-all picture. The book is based on a course of lectures given in the advanced engineering program of the General Electric Company, Schenectady, N. Y.

Mathematical and Physical Principles of Engineering Analysis. By W. C. Johnson. McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1944. 346 pages, illustrated, 8½ by 5 inches, cloth, $3. (ESL.)

This book is the outgrowth of a recent course given at Princeton University. Its purpose is to present the physical and mathematical principles and methods of approach that underlie the analysis of many practical engineering problems. The viewpoint is practical and utilitarian. Emphasis is placed upon physical concepts, the use of assumptions, procedures in setting up equations, the use of mathematics as a tool in accurate quantitative reasoning, and the physical interpretation of mathematical results.

Mathematische Grundlagen der Quantenmechanik. By J. von Neumann. Dover Publications, New York 16, N. Y., 1943. 266 pages, illustrated, 9½ by 6 inches, cloth, $3.50. (ESL.)

Neumann's, "Mathematical Bases of Quantum Mechanics," long has been esteemed by mathematicians and physicists for its thorough logical development and discussion of the subject. The present American edition has been produced, in response to demand, under license by the Alien Property Custodian. The latest German edition is reproduced with the addition of a German–English glossary.

Mechanical Properties of Metals and Alloys. (Circular of the National Bureau of Standards *C*447.) By J. L. Everhart and others. United States Government Printing Office, Washington, D. C. 481 pages, illustrated, 11 by 8 inches, cloth. $1.50. (ESL.)

This circular is a summary of the data available on the strength and related properties, thermal expansion, and thermal and electric conductivities of ferrous and nonferrous metals and alloys at normal, high, and low temperatures. Included are many metals and alloys which ordinarily are not considered as engineering materials. The data are presented in tables or graphs, and the source of each given.

Practical Analytic Geometry With Applications to Aircraft. By R. A. Liming. The Macmillan Company, New York, N. Y., 1944. 277 pages, illustrated, 8½ by 5½ inches, linen, $4.50. (ESL.)

This book is a comprehensive presentation of the application of analytic geometry to the practical mathematical definition of airplane contours and structure. Part one analyzes applications to two-dimensional space. Part two develops the application of rectangular co-ordinates to three-dimensional space. Part three applies a system of analytic analysis to curves commonly required in the lofting of streamline bodies. Although the book deals exclusively with aircraft structures, the principles developed apply equally to such related fields as the automotive and marine industries.

Abstracts on Synthetic Rubber, Part I—Articles (NRC 1136) 362 pages. Part II—Patents (NRC 1137) 200 pages. National Research Council of Canada, Ottawa, Ont., June 1943. Tables, 11 by 8½ inches, paper, manifold, $2 each. (ESL.)

This publication provides abstracts of over 800 articles and over 700 patents dealing with synthetic rubber, as well as a list of 123 articles and books that are not abstracted. A subject index to the abstracts and an index of patentees are included.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Power for Mechanized War. National Electrical Manufacturers Association, 155 East 44th Street, New York 17, N. Y., 19 pages.

Program and Progress Report. Smaller War Plants Corporation, Washington, D. C., 58 pages.

Fifteenth Report to Congress on Lend-Lease Operations. Superintendent of Documents, United States Government Printing Office, Washington 25, D. C., 84 pages, 30 cents.

Adjustment of Production Cut-Backs. Army Service Forces, War Department, Washington, D. C., unpaged.

Dow and Magnesium. Dow Chemical Company, Midland, Mich., 76 pages.

How Quartz Crystals Are Manufactured. North American Philips Company, Inc., 100 East 42nd Street, New York 17, N. Y., 36 pages.

The Coming Battle of Materials. Dohner and Lippincott, 500 Fifth Avenue, New York 18, N. Y., unpaged.

NAM News Tax Supplement. National Association of Manufacturers, 14 West 49th Street, New York 20, N. Y., 16 pages, free to members, 10 cents per copy, $9 per hundred copies.

The Financial Situation of Industry After Two Years of War. C. C. Abbott, 25 pages, 25 cents. **Business Finances During the Critical Transition From War to Peace.** C. C. Abbott, 41 pages, 50 cents. Division of Research, Graduate School of Business Administration, Harvard University, Cambridge, Mass.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

A Graphical Analysis of the Voltage and Current Wave Forms of Controlled Rectifier Circuits

P. T. CHIN
ASSOCIATE AIEE

E. E. MOYER
MEMBER AIEE

Synopsis: Controlled rectifiers employing gaseous discharge tubes are used more and more frequently in the industrial field owing to the ease of control of the output voltage and the high conversion efficiency. The voltage and current wave forms at the different parts of controlled rectifier circuits are often non-sinusoidal and discontinuous due to the one-way valve-action of the rectifying elements. This paper presents a graphical method of constructing the voltage and current wave forms based on a few well-known fundamental principles of electrical engineering. This method is presented step by step and a few typical examples are shown to illustrate its validity.

1. Introduction

CONTROLLED rectifiers, either thyratron-tube or ignitron-tube equipments, are becoming more and more frequently used to obtain regulated sources of d-c from an a-c supply, both for d-c power requirements and for control purposes.

When the regulated source of d-c requires only a few kilowatts of power, the single-phase rectifier circuit is preferable because of its economical use of tubes and associated apparatus and because of the simplicity of its control circuits. In addition, the single-phase circuit is probably easier for the beginner to understand, and once its fundamental principles of analysis are mastered they can be extended readily to polyphase rectifier circuits.

Comparatively little material is available in current literature on the subject of controlled rectifiers, and in particular on the analysis of voltage and current wave forms at different parts of the circuit. Rectifier-circuit analysis is difficult because nonsinusoidal wave forms, which often involve discontinuities, are produced by the one-way controlled-valve action of the gaseous-discharge-tube rectifying elements.

A knowledge of these voltage and current wave forms is necessary to predict the nature of the output which can be obtained from a particular circuit and load combination, and to select elements of the correct ratings for the voltages and currents encountered. Furthermore, a mathematical analysis of these circuits presupposes a physical picture of the circuit behavior.

In order to show the significance of voltage and current wave forms with respect to each circuit element, consider the single-tube rectifier supplying a load comprising an inductance in series with a resistance as shown in Figure 1a. Such a load is typical of the field winding of a dynamo-electric machine, the coil of a contactor or relay, and the windings of clutches and solenoids. Figure 1b shows the instantaneous distribution of voltage across the four elements of the circuit, namely, anode-transformer secondary winding, rectifying element, inductance, and resistance.

Figure 2a to e, inclusive, shows the wave forms of voltage and current at the individual elements of the circuit of Figure 1. Figure 2b is the wave form of the output voltage of this half-wave rectifier circuit. In practice, as in the case of a coil whose inductance has inevitable resistance, the voltage across L cannot be segregated from the voltage across R so that each voltage can be observed separately. It is from the picture of Figure 2b that the wave forms of Figure 2c, d, and e are most readily derived.

Table I summarizes the significance of each picture of Figure 2 with respect to those features which are important to each circuit element.

In the presentation which follows, each of the fundamental principles is stated and the examples are analyzed by the application of these principles. The analysis is based on the following assumptions:

A. Linear circuit elements, R–L–C.

B. Transformer leakage reactance and resistance and the internal resistance and reactance of a counter electromotive force are neglected.

C. The solution is that of the steady state, although this method can be extended to transient analysis as is shown by the example of Figure 14a.

2. Fundamentals of Analysis

The several fundamental principles of circuit analysis which will be used throughout this discussion are stated herewith. Each principle is given a number by which it is referred to in the examples which follow.

2.1. Kirchhoff's Laws

2.11. *Voltage.* The summation of the instantaneous voltages around a closed circuit is equal to zero.

Referring to Figure 1b, it is shown that the instantaneous transformer voltage is equal to the sum of the respective voltages, at that same instant, across the tube, the inductance, and the resistance.

2.12. *Current.* The summation of the instantaneous currents at a given point equals zero.

2.2. The Resistor—Its Voltage-Current Relations

A pure resistor cannot store energy; it can only dissipate energy.

The energy consumed by a resistor is dissipated in the form of heat. This energy is expressed in watt-seconds, or joules, if e_R is in volts and i in amperes according to the relation:

$$\text{Energy} = \int e_R i \, dt$$

The power consumed by a resistor, or, the rate of energy dissipation, is equal to

Paper 44-75, recommended by the AIEE committee on electrical machinery for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944. Manuscript submitted February 21, 1944; made available for printing March 8, 1944.

P. T. Chin and E. E. Moyer are in the electronics section, industrial control engineering division, General Electric Company, Schenectady, N. Y.

$e_R i$ and is measured in watts if e is expressed in volts and i in amperes.

2.21. Both the current flowing through a resistor and the voltage across the resistor can be changed instantaneously.

2.22. The voltage drop across a resistor is always of such polarity as to oppose the flow of current through the resistor.

2.23. In a resistor, the voltage and the current have the following relation:

$$e_R = R\,i$$

2.3. The Inductor—Its Voltage-Current Relations

A pure inductor cannot dissipate energy.

Energy can be stored in the electromagnetic field of an inductor so long as current is flowing in the winding. This energy is expressed in watt-seconds if the inductance is in henrys and the current in amperes according to the relation:

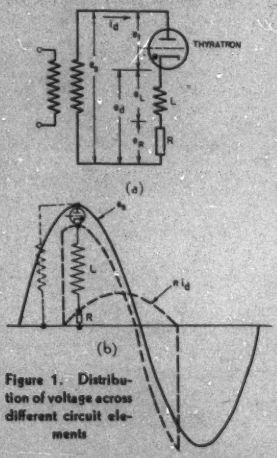


Figure 1. Distribution of voltage across different circuit elements

$$\text{Energy} = \tfrac{1}{2}Li^2$$

Thus, in a given inductance of L henrys, the square of the current at any instant is a measure of the energy stored therein.

2.31. The energy stored in an inductor cannot be changed instantaneously; therefore, the current through the inductor cannot be changed instantaneously.

The voltage across an inductor can be changed instantaneously (a change of voltage is not a change of energy).

2.32. *Lenz's Law.* The polarity of the induced voltage across an inductor is always such as to oppose the change of current through the inductor.

That is, the polarity of the induced voltage cannot be determined from the direction of flow of current alone, but also depends on whether the current is increasing or decreasing. With the direction of flow of current as in Figure 3a, if the current is increasing the polarity of the induced voltage will be as shown in Figure 3b; if the current is decreasing the polarity will be as shown in Figure 3c; if the current is not changing there will be no induced voltage. The induced voltage is always equal and opposite to the impressed voltage.

2.33. In an inductor, the impressed voltage and the current have the following relation:

$$e_L = L\frac{di}{dt}$$

From this fundamental equation several useful conclusions can be drawn concerning the relation between the impressed voltage and the current of an inductor.

2.331. The slope of the current (di/dt in amperes per second) at any point equals the inductor voltage (volts) divided by the inductance (L henrys).

2.332. The current is either a maximum or a minimum when the inductor voltage is equal to zero.

Proof: i = maximum or minimum when $di/dt = 0$, that is, when $e_L = 0$

In Figure 4, the currents at t_2, t_8, t_{10}, t_{14} are maxima; the currents at t_4, t_6, t_{12} are minima. The voltages corresponding to these currents are equal to zero.

2.333. The current has a point of inflection when the voltage is either a maximum or a minimum.

Proof: If e_L = maximum or minimum, then the slope at that point must be either a maximum or a minimum.

In Figure 4, the current has a point of inflection at t_1, t_3, t_5, t_7, t_9, t_{11}, t_{13} and the inductance voltage has either a maximum or a minimum at these points.

2.334. The change of current from a value i_1 at a time t_1 to a value i_2 at a time t_2 is equal to the time integration of the inductance voltage between t_1 and t_2 (expressed in volt-seconds) divided by the inductance (expressed in henrys).

Proof:

$$\int_{i_1}^{i_2} di = \frac{1}{L}\int_{t_1}^{t_2} e_L\,dt$$

$$i\Big]_{i_1}^{i_2} = \frac{1}{L}\int_{t_1}^{t_2} e_L\,dt = i_2 - i_1$$

In Figure 4, the difference between the currents at t_2 and at t_6, that is, $i_6 - i_2$, is equal to

$$\frac{1}{L}(-A_3 + A_1)$$

2.3341. The current at any instant t_2 is equal to the time integration of the voltage divided by the inductance if the current equals zero at t_1.

Proof:

$$i_2 = \int_{t_1}^{t_2} e_L dt \text{ because } i_1 = 0$$

In Figure 4, $i_2 = \dfrac{A_1}{L}$ since $i_6 = 0$.

2.3342. If the current at t_1 is equal to the current at t_2, the time integration of the voltage during the interval between t_1 and t_2 must be equal to zero.

Proof: if $i_1 = i_2$ then

$$\frac{1}{L}\int_{t_1}^{t_2} e_L dt = i_2 - i_1 = 0$$

In Figure 4, if $i_{10} = i_{14}$, then $A_6 = A_7$.

2.335. The current wave is a smooth curve (no sudden change of slope) if there is no sudden change of voltage. The current wave is not a smooth curve (sudden change of slope) if there is a sudden change of voltage.

The current wave of Figure 4 is a smooth curve since there is no sudden change of voltage. The current wave of Figure 5 is not a smooth curve since there is a sudden change of voltage at t_3, t_5, t_9.

2.4. The Capacitor—Its Voltage-Current Relations

A pure capacitor cannot dissipate energy.

Energy can be stored in the electrostatic field of a capacitor so long as a potential is present across its terminals. This energy is expressed in watt-seconds if the

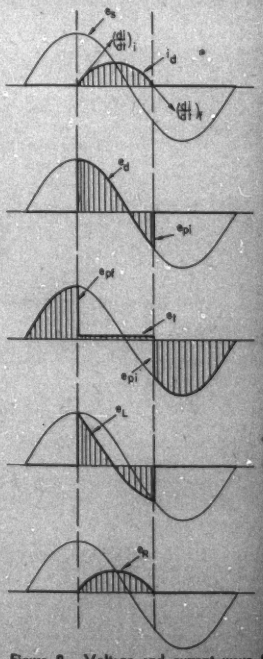


Figure 2. Voltage and current wave form

Table I. Significant Features of Wave Forms of Figure 2 With Respect to Each Circuit Element

Figure	Tube	L	R	C	Transformer
2a	Peak current Average current Initial and final rate change of current	Average current	Rms current		Rms current
2b		Average voltage output (actually L and R are inseparably combined as in coil)			
2c	Peak inverse voltage conduction period				
2d		Peak voltage			
2e			Same as Figure 2a plotted in terms of iR drop		

capacitance is in farads and the potential in volts according to the relation:

$$\text{Energy} = {}^1/_2 Ce_C^2$$

Thus, in a given capacitance of C farads, the square of the voltage at any instant is a measure of the energy stored therein.

2.41. The energy stored in a capacitor cannot be changed instantaneously; therefore, the potential across the capacitor cannot be changed instantaneously.

The current "through" a capacitor can be changed instantaneously (a change of current is not a change of energy).

2.42. The direction of flow of current in a capacitor cannot be determined from the polarity of the voltage across the capacitor alone, but also depends on whether the voltage is increasing or decreasing.

The voltage across the capacitor always changes in such a way as to oppose the flow of current through the capacitor. Therefore, in Figure 6b the current flows from "2" to "1" if the voltage is increasing; current flows from "1" to "2" if the voltage is decreasing; if the voltage is not changing there will be no current flow.

2.43. In a capacitor, the voltage and the current have the following relation:

$$= C\frac{de_C}{dt}$$

From this fundamental equation several useful conclusions can be drawn concerning the relation between the voltage and the current of a capacitor.

2.431. The slope of the voltage (de_C/dt, in volts per second) at any point equals the capacitor current (amperes) divided by the capacitance (C farads).

2.432. The voltage is either a maximum or a minimum when the current is equal to zero.

Proof: e_C = maximum or minimum when $de_C/dt = 0$, that is, when $i = 0$

In Figure 8, the voltage e_{C1} at t_1 is a maximum and the current i_1 at t_1 is equal to zero.

2.433. The voltage has a point of inflection when the current is either a maximum or a minimum.

Proof: If i = maximum or minimum, then the slope of the voltage must be either a maximum or a minimum.

In Figure 7, the voltage wave at t_1, t_4, t_7, t_{10} has a point of inflection when the current has maximum values at these corresponding instants.

2.434. The change of voltage from a value e_1 at a time t_1 to a value e_2 at a time t_2 is equal to the time integration of the capacitance current between t_1 and t_2 (expressed in ampere-seconds, or coulombs) divided by the capacitance (expressed in farads).

Proof:

$$\int_{e_C}^{e_{C2}} de_C = \frac{1}{C}\int_{t_1}^{t_2} i\,dt$$

$$\Big]_{e_{C1}}^{e_{C2}} e_C = \frac{1}{C}\int_{t_1}^{t_2} i\,dt = e_{C2} - e_{C1}$$

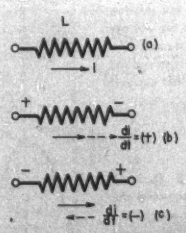


Figure 3. Determination of the polarity of the induced voltage in an inductor

In Figure 8, the difference between the voltages at t_0 and at t_3, that is, $e_{C3} - e_{C0}$, is equal to

$$\frac{1}{C}(+A_1 - A_2)$$

2.4341. The voltage at any instant t_1 is equal to the time integration of the current divided by the capacitance if the voltage equals zero at t_1.

Proof:

$$e_{C1} - e_{C1} = \frac{1}{C}\int_{t_1}^{t_1} i\,dt = e_{C1}$$

because $e_{C1} = 0$.

In Figure 7, $e_{C1} = \dfrac{A_1}{C}$ since $e_{C0} = 0$.

2.4342. If the voltage at t_1 is equal to the voltage at t_2, the time integration of the current during the interval between t_1 and t_2 must be equal to zero.

Proof: if $e_{C1} = e_{C2}$ then

$$\int_{t_1}^{t_2} i\,dt = e_{C2} - e_{C1} = 0.$$

In Figure 8, if $e_{C3} = e_{C0}$ then $A_3 = A_1$.

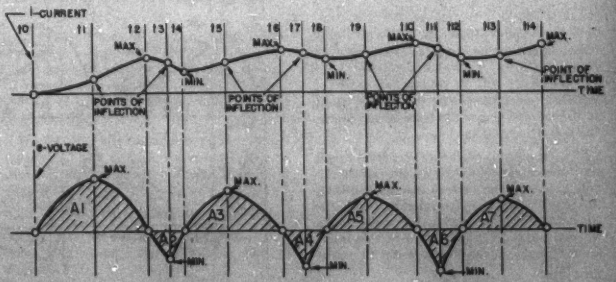
2.435. The voltage wave is a smooth curve (no sudden change of slope) if there is no sudden change of current. The voltage wave is not a smooth curve (sudden change of slope) if there is a sudden change of current.

The voltage wave of Figure 7 is a smooth curve since there is no sudden change of current. The voltage wave of Figure 8 is not a smooth curve since there is a sudden change of current at t_0, t_3, t_6.

2.5. The Rectifying Element—Its Voltage-Current Relations

The rectifying element considered throughout this discussion is of the gaseous-discharge type—the thyratron or the ignitron.

Figure 4 (below). Graphs showing the relation between the voltage across and the current through an inductor



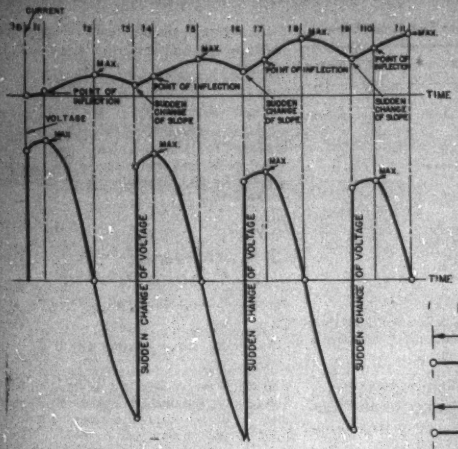


Figure 5. Graphs showing the relation between the voltage and current in an inductor (sudden change of voltage)

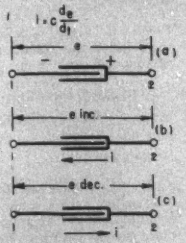


Figure 6 (below). Determination of the direction of current flow in a capacitor

2.51. Before the tube fires and before the current begins to flow, the tube acts as an open switch.

It is assumed that the striking voltage at which gaseous conduction begins is the arc-drop voltage (actually, the striking voltage may be more than arc-drop voltage,[2] say two or three times arc drop voltage). That is, it is assumed that gaseous conduction (as distinguished from electron space current before ionization occurs) begins as soon as the anode is positive with respect to the cathode by an amount equal to the arc drop.

In a thyratron, the actual firing point[3] is dependent upon anode voltage, grid voltage, and tube characteristic. In this discussion, the manner of controlling the firing point is incidental; only the results of the controlled tube as a circuit element are considered.

2.52. After the tube fires, the voltage across the tube is its arc drop which is practically independent of current. In this discussion, the arc drop during conduction is assumed to be constant.[4]

After the tube fires, the current through the tube is limited only by the combination of circuit elements in series with the tube, including any counter electromotive forces.

2.53. The voltage across the tube is equal to the voltage across the transformer minus the voltage across the load.

2.54. The gaseous discharge current through the tube ceases when the circuit causes the voltage across the tube to become less than the tube's arc drop. (In ignitron tubes without holding-anodes, the anode current ceases when the current falls below a certain minimum value necessary to maintain the cathode spot.)

2.6. The Load—Its Voltage-Current Relations

The load is a combination of R, L, C with or without a counter electromotive force.

2.61. The voltage across the load, when a tube is conducting, follows the supply-voltage wave-form (minus arc drop).

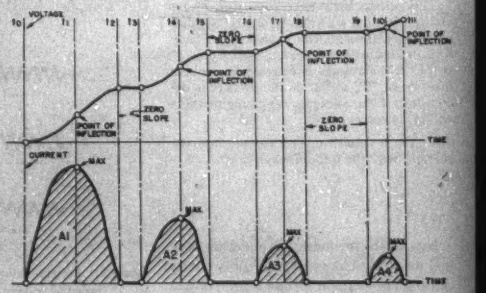
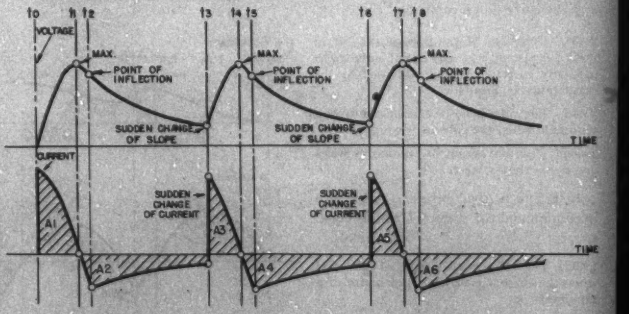


Figure 7. Graphs showing the relation between the voltage and the current in a capacitor (no sudden change of current)

Figure 8 (below). Graphs showing the relation between the voltage and current in a capacitor



2.62. The voltage across the load, when no tube is conducting, depends on the nature of the load and whether a counter electromotive force or parallel load path is present. This is shown in Figures 9a, b, and c, respectively.

2.63. The relation between voltage and current at the load is complicated, but the approximate wave form of the current, in relation to the voltage, can be sketched by the application of these principles.

3. Examples

3.1. The pure inductance of L henrys (zero resistance) supplied from a single-tube, half-wave, controlled rectifier, fired at 60 degrees and having a peak anode voltage of E_{gp} volts. This circuit is shown in Figure 10k.

Procedure

3.11. Sketch in the sine wave of secondary voltage e_s as in Figure 10a.

3.12. Then, the extinction point of the current will be 360—60 degrees since equal positive and negative areas of voltage must appear across the inductor whose current begins at zero and ends at zero. Figure 10b. Principle 2.3342.

3.13. Draw the voltage wave across the inductor. Figure 10c. Principle 2.6.

3.14. Sketch the inverse voltage of the tube. This is the transformer voltage minus inductor voltage. Figure 10d. Principle 2.53.

3.15. Determine the initial slope of the current wave. Principle 2.33.

This may be done graphically by constructing a right-angle triangle whose verti-

cal side is the voltage at this instant and whose horizontal side is L. Choose a convenient length for L, what length merely determines the scale of the current curve. Figure 10e. Principle 2.331.

3.16. Determine the final slope of the current wave in the same manner as for the initial slope. Figure 10e.* Principle 2.331.

3.17. Determine the peak value of the current wave (principle 2.3341) which occurs at the 180-degree point (principle 2.332) by calculating or estimating (for example, counting squares) the area underneath the positive half cycle of inductor voltage and dividing this area by the inductance. Figure 10f.

3.18. If necessary, additional points for the curve can be obtained by estimating the area up to a given point and dividing by L. Figure 10g and h. Principle 2.334.

3.19. The effect of arc drop can be determined from principle 2.52 by subtracting volts of arc drop from the inductor voltage. Figure 10i.

The peak current now occurs before the 180-degree point and this current wave is unsymmetrical, that is, the final slope differs from the initial slope. Figure 10j.

3.191. Figure 10l, m, and n show the voltage and current wave forms of a pure inductance supplied by a single-tube half-wave rectifier fired at different points.

3.2. An inductance of L henrys and a resistance of R ohms in series supplied from a single-tube half-wave controlled rectifier, fired at 60-degrees and having a peak anode voltage of E_{pi}, volts. This is the circuit of Figure 11h.

PROCEDURE†

3.21. Sketch in the sine wave of secondary voltage e_s as in Figure 11a.

3.22. Find the initial slope of the IR-voltage wave (which is proportional to the current). Principle 2.331. In this instance, the slope is constructed from the right-angle triangle whose vertical height is E_{pi}, volts and whose horizontal length is L/R seconds. Figure 11b.

3.23. Assume a peak value of IR voltage which peak value will fall along the positive-decaying-portion of the inductor voltage wave. Sketch in the IR-voltage wave, roughly. Its slope will be horizontal at the point of crossing the inductor voltage wave. Figure 11c. Principle 2.332.

3.24. Measure the area between the inductor-voltage curve and the IR-voltage curve. Divide this area (volt-seconds) by the time constant L/R (seconds) to determine the peak value of IR. If this calculated value of IR does not agree closely with the assumed value of 3.23 repeat 3.23 and 3.24 with a more accurate value until the value chosen in 3.23 and the value calculated in 3.24 agree closely. Figure 11d. Principle 2.334.

3.25. Find the extinction point by assuming a point such that the negative voltage area between the IR curve and the e_s curve equals the positive area of 3.24. Figure 11e. Principle 2.3342.

If the first assumption is not correct, repeat with more accurate values until the areas are equal.

3.26. If more accuracy is required, intermediate points can be drawn as shown in Figure 11f and g

3.27. The inverse voltage across the tube can be drawn as in 3.14.

Find the average value of this voltage wave. This average will be a value which will give equal positive and negative shaded areas, as shown.

For current to be continuous, the end of the negative shaded area should coincide with the beginning of the successive positive area.

If the counter electromotive force is higher than this average voltage level, continuous current will be impossible. This is shown in Figure 12f.

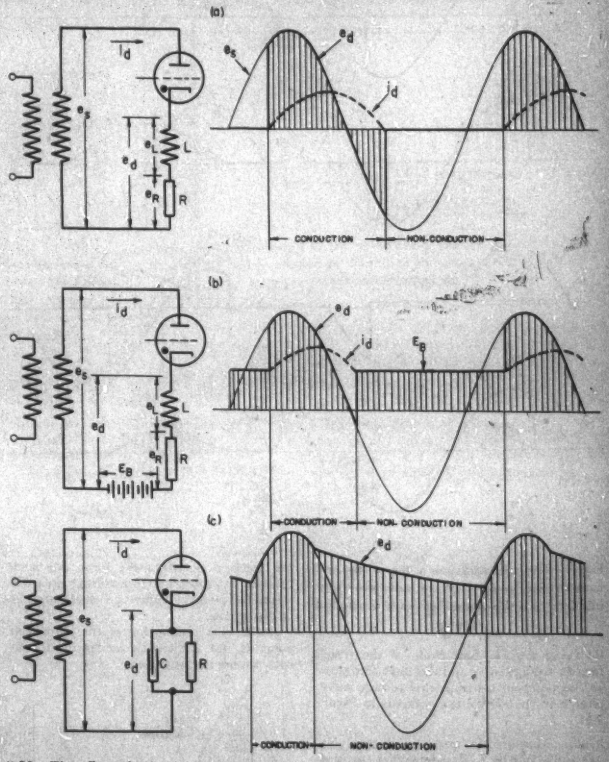


Figure 9. Voltage across the load

3.28. The effect of tube drop can be shown by subtracting arc drop from the inductor-voltage wave as in paragraph 3.19, then re-estimating the areas based on the new inductor-voltage wave.

3.3. The L–R load with counter electromotive force. Supplied from a two-tube biphase half-wave controlled rectifier, fired at 60 degrees and having an anode-to-neutral voltage of E_{pi}, volts. This circuit is shown in Figure 12g.

3.31. Sketch the transformer-voltage waves e_{s1} and e_{s2} and draw in the counter-electromotive force voltage to the same scale as in Figure 12a.

3.32. Test for current continuity as follows:

3.321. If the current is continuous, the total load voltage should be like that of Figure 12b.

3.322. If the current is discontinuous, the total load voltage should look like that of Figure 12f which has very definite regions of zero current when the output voltage is the counter electromotive force. Principle 2.62.

The average value of this voltage wave will be found to be higher than the counter-electromotive force level.

3.33. Assuming the discontinuous current case of paragraph 3.322, draw the transformer voltage waves and the counter electromotive force as in Figure 12a.

3.331. Draw the initial slope of the IR voltage wave as in Figure 12c.

3.332. Assume a peak value of the IR voltage wave. This peak value will fall along the

* In Figure 10e, the value of L was taken to be so many units of length. Each square of area is voltage height times a base width, so, the division of total squares of area by base divisions of L will give a measure of current.

† In the sketches which follow, the current is proportional to IR drop and is sketched in terms of IR drop.

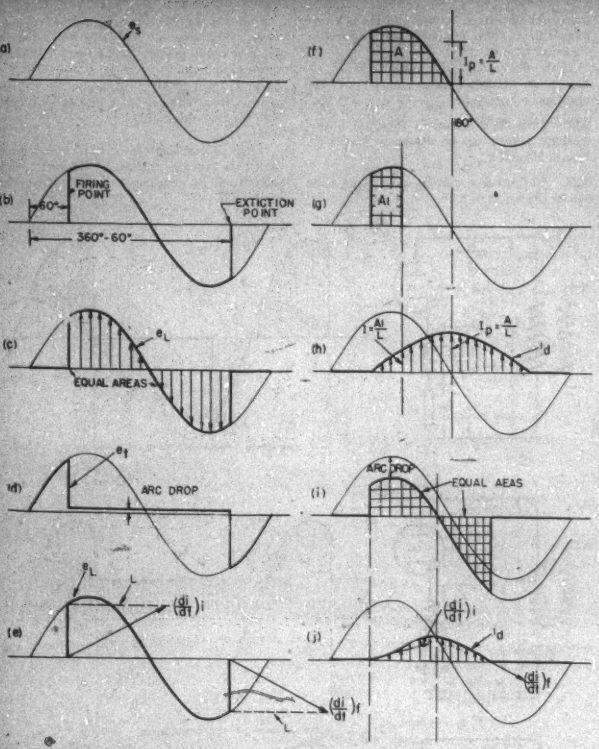


Figure 10a–j. Construction of the voltage and current wave forms of a pure inductance supplied by a single-phase half-wave controlled rectifier

decaying positive half cycle of the transformer-voltage wave and will have zero slope at the point of crossing this voltage wave. Sketch in the *IR* voltage wave as in Figure 12d.

3.333. Measure the area of inductor voltage and divide by L/R to determine the peak value of *IR* voltage at this point. If this calculated value of *IR* does not agree with the assumed value of 3.332, repeat 3.332 and 3.333 using an assumed value which is more accurate. Figure 12d.

3.334. Determine the extinction point of the *IR* voltage wave. This point will lie on the counter electromotive force line such that the negative inductor-voltage area will equal the positive inductor-voltage area as in Figure 12e.

If the first assumption of the extinction point is not sufficiently accurate, repeat with a more accurate value.

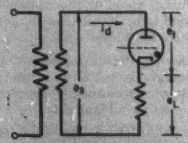


Figure 10k. Circuit diagram of a single-phase half-wave controlled rectifier supplying a purely inductive load

As a further refinement, intermediate points can be determined as in paragraph 3.26.

3.335. Check the final slope of the current wave as being the triangle formed by e_s and L/R.

3.336. If desired, the effect of tube drop can be found as in paragraph 3.19.

3.337. The tube inverse voltage can be found as in paragraph 3.14.

3.338. Find the average output voltage by averaging the counter electromotive force plus the *IR* drop.

3.34. Assuming the continuous-current case of paragraph 3.321, draw the transformer voltage waves, the firing point and corresponding average voltage line, the voltage across the load, and the counter electromotive force line as in Figure 13a.

3.341. Construct the *IR* drop about the average voltage line. This is done by assuming an initial value of *IR* drop which is approximately, but not exactly, midway between the average voltage line and the counter electromotive force line. This initial *IR* drop is therefore negative with respect to the average voltage line (that is, below the average voltage line) but positive with respect to the counter electromotive force line (that is, above the counter electromotive force line).

3.342. Draw the initial slope of the *IR* voltage wave based on this assumed initial value of *IR* drop. Figure 13b.

3.343. Assume a peak value of *IR* voltage which will fall along the positive-decaying portion of the transformer voltage wave and will have zero slope at the point of crossing this voltage wave.

Sketch in the *IR* voltage wave as in Figure 13b and c.

3.344. Measure the area of inductor voltage. Divide this area, A_1 in Figure 13d, by

Figure 10l–n. Voltage and current wave forms of a single-phase half-wave rectifier supplying a pure inductance firing at different points

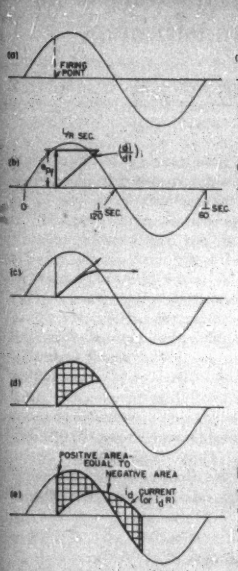


Figure 11. Construction of the voltage and current wave forms of an L–R load supplied by a single-phase half-wave controlled rectifier

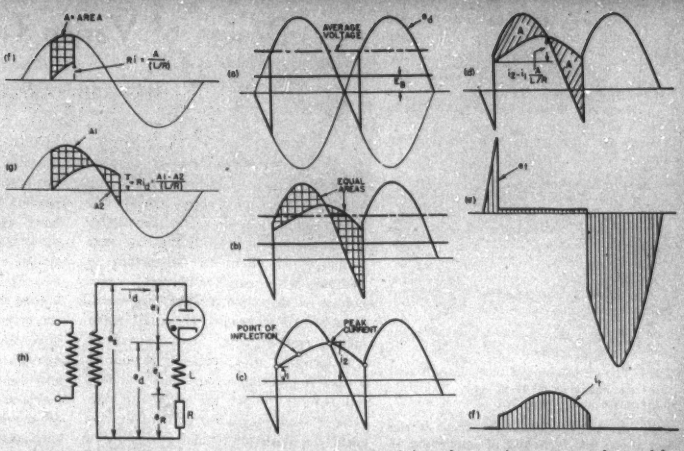


Figure 13. Construction of the voltage and current wave forms of L, R, and E_B in series supplied by a biphase half-wave controlled rectifier (continuous current)

L/R seconds to obtain the increased value of IR at this instant. The increased value of IR is measured from the level of the initial value.

If this estimated value of IR does not agree with the assumed value of paragraph 3.343, repeat the operation of paragraph 3.343 with a more accurate value.

3.345. The extinction point of IR drop must coincide with the initial value of IR drop as in paragraph 3.341.

Check that the positive and negative inductor-voltage areas are equal as in Figure 13d. Make repeated tries until sufficient correspondence is achieved.

3.346. Check the final slope of the IR curve by dividing the final IR drop by L/R.

3.347. As a check, the average value of the counter electromotive force plus IR drop should equal the average output voltage of the rectifier when fired at the assumed 60-degree point.

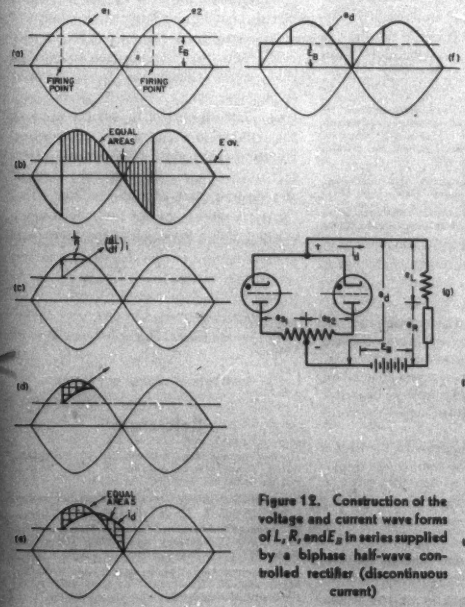


Figure 12. Construction of the voltage and current wave forms of L, R, and E_B in series supplied by a biphase half-wave controlled rectifier (discontinuous current)

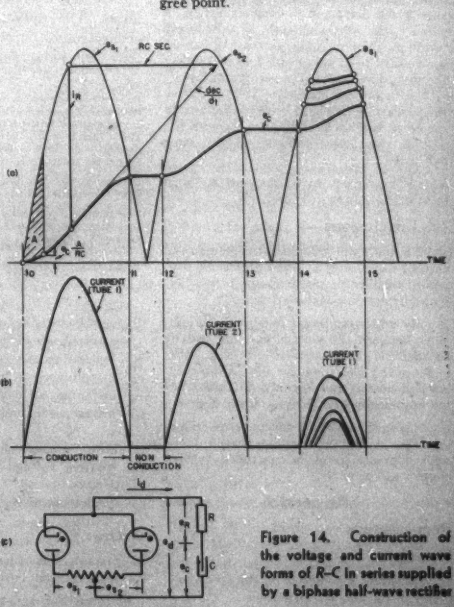


Figure 14. Construction of the voltage and current wave forms of R–C in series supplied by a biphase half-wave rectifier

3.348. As another check, the IR drop should have equal areas about the average voltage line.

3.349. The effect of tube drop can be considered as in paragraph 3.19.

Tube inverse voltage can be found as in Figure 13e.

Note the double inverse voltage wave form.

Tube current is shown in Figure 13f.

3.4. A capacitor of C farads in series with a resistor of R ohms and supplied from a two-tube bi-phase half-wave rectifier whose peak anode voltage is E_{pa}, volts. This circuit is shown in Figure 14c.

Figure 14a shows the transient build-up of voltage across the capacitor when started from an initial, discharged condition.

3.41. Sketch the positive half-cycles of transformer voltages as in Figure 14a.

3.42. The initial slope of the voltage is zero since the initial current is zero. Principle 2.431.

3.43. Assume a capacitor voltage at the end of the first half-cycle of conduction at t_1, and sketch in the capacitor voltage wave.

3.44. Measure the area corresponding to the time integration of IR voltage. Divide this area (expressed in volt-seconds) by the time constant RC (expressed in seconds) to determine the capacitor voltage at t_1. It should check with the value assumed in paragraph 3.43; if not, repeat the procedure with a more accurate value in paragraph 3.43.

For more accurate results, a few intermediate points can be estimated by integrating the IR drop only up to these points.

3.45. At t_1 tube 1 ceases to conduct and tube 2 will not begin to conduct until e_{g2} is equal to e_{c1}. Starting from t_1, tube 2 will conduct. Assume a new increase of capacitor voltage as in paragraph 3.43 and repeat the procedure outlined in paragraph 3.44.

The build-up of capacitor voltage during the successive four half-cycles are shown in the third half-cycle of Figure 14a with the voltage wave superimposed on the same half-cycle.

3.46. The current wave forms can be drawn from Figure 14a as in Figure 14b.

4. Conclusions

A. The ability of predicting the voltage and current wave forms at different parts of controlled rectifier circuits is essential to a better understanding of these circuits.

B. By understanding a few basic relationships between the voltage and the current through the circuit elements—L, R, C, tube, and counter electromotive force—the voltage and current wave forms can be constructed graphically to a fairly accurate degree.

C. It is the intention of this paper to stimulate the general interest so that a more rigorous treatment of the controlled rectifier circuits will be made.

Appendix

Nomenclature

VOLTAGE

e_s—instantaneous voltage on the secondary side of the anode transformer

E_{ps}—peak value of the voltage on the secondary side of the anode transformer

e_R—instantaneous voltage across a resistor

e_L—instantaneous voltage across an inductor

e_C—instantaneous voltage across a capacitor

e_T—instantaneous voltage across the rectifier

e_d—instantaneous voltage across the load

E_B—battery voltage or counter electromotive force

e_{pf}—peak forward voltage

CURRENT

i_d—instantaneous current through the load

i_T—instantaneous current through the rectifier

$\left(\frac{di}{dt}\right)_i$—initial rate of change of current

$\left(\frac{di}{dt}\right)_f$—final rate of change of current

Design of Variac Transformers

EDUARD KARPLUS
MEMBER AIEE

MOST textbooks on transformers mention in a few concluding paragraphs that for certain applications special transformers can be used to good advantage. Foremost among these is the autotransformer which offers very important advantages if the ratio of input to output voltage is close to unity. Other special transformers mentioned are small instrument transformers, constant-current transformers, and voltage regulators. Voltage regulators are ordinarily divided into several groups: the automatic magnetic-flux-type regulator without moving parts, the induction regulator with one of its windings mounted so that it can be turned into different positions with respect to the other windings, and the tap-changing type, which requires special precautions if voltage has to be changed under load.

In power-distribution systems, a certain amount of flexibility is required to provide constant voltage to the ultimate consumer regardless of his distance from the station and regardless of load, and some feeder lines are connected to individual hand-operated or automatic regulators. The regulators are ordinarily tap-changing autotransformers or boosters, or they are induction regulators. While variable-ratio transformers of high rating have been manufactured for these applications by practically every one of the large transformer companies, smaller units have not been available until recently. It is the purpose of this paper to describe a variable-ratio transformer[1] intended primarily for low power. When the first Variac, the continuously adjustable variable-ratio autotransformer, was introduced in 1933, it found immediate acceptance. Today close to one million transformers of this type are in use. They are available from several manufacturers with ratings from 100 to 10,000 volt-amperes. Three transformers, as manufactured by General Radio Company, Cambridge, Mass., are shown in Figures 1–3.

Paper 44-87, recommended by the AIEE committee on electrical machinery for presentation at the AIEE North Eastern District technical-meeting, Boston, Mass., April 19–20, 1944. Manuscript submitted February 29, 1944; made available for printing March 20, 1944.

EDUARD KARPLUS is development and design engineer, General Radio Company, Cambridge, Mass.

The analysis of optimum contact resistance in the equivalent contact circuit has been contributed by Doctor W. N. Tuttle.

Description

As the name Variac implies, the new transformer provides "variable a-c voltage" when connected to a power line. The basic principle is that of a tap-changing autotransformer. The tap-changing mechanism is the essential part of this transformer and the simplicity of this mechanism is responsible for its success. The "taps" are formed by exposed parts of the winding that is applied in a single layer over a toroidally shaped-iron core. The number of taps is the same as the number of turns of the transformer. Rotation of the control shaft causes a contact to traverse these turns and to tap off any desired part of the winding. The turns are closely spaced and the contact is wide enough to engage at least one turn

References

1. RECTIFIER-CIRCUIT DUTY, C. C. Herskind. AIEE TRANSACTIONS, volume 63, 1944, March section, pages 123–8.

2. RCA-2050 TUBE DATA, AVERAGE CONTROL CHARACTERISTICS. RCA Tube Handbook HB-3.

3. APPLIED ELECTRONICS (a book), Massachusetts Institute of Technology staff. John Wiley and Sons, 1943, pages 308–9.

4. MERCURY-ARC RECTIFIERS (a book), O. K. Marti and H. Winograd. McGraw-Hill Book Company, 1930, page 22.

at all times. It is possible, therefore, to move the contact under load without interrupting the circuit. To engage at least one turn at all times, the contact must be wider than the spacing between turns and it follows that turns can be short-circuited by the contact. To prevent damage to the winding, the contact is made of resistive material that limits the circulating current in the short-circuited turn. Since the load current has to flow through the contact, the resistance is kept as low as possible. The problem encountered is very similar to the problem of commutation in generators or motors, and the materials used for the contact are the same that are used in the familiar carbon brushes of rotating machines. The Variac transformer is designed to stand indefinitely the additional heat produced in the short-circuited turn and no attempt is made to prevent the contact from resting between turns. On the contrary, short-circuiting turns is one of the important advantages of the Variac, as it affords a gradual change from one tap to the other. Ordinarily, the voltage-per-turn is between one-half volt and one volt.

Uses

The advantages of the variable-ratio autotransformer over rheostats and other kinds of voltage-control devices are high efficiency, good regulation, and linear smooth control from zero to above line voltage. Mechanically the transformer is small in size and simple in construction.

In industrial control and in experimental problems in the laboratory, Variacs are used wherever alternating voltages must be adjusted, and by means of voltages, other quantities such as speed, heat, or light. Typical applications are speed control of motors, heat control of electric furnaces or heaters in a laboratory, illumination control in small theaters or dark rooms, output voltage control of high-voltage transformers and rectifier systems, filament control for radio-transmitter tubes, and voltage control for electrical or magnetic testing, calibration, and measurement.

Contact Problems

As mentioned before, the transformer uses a carbon brush, called the contact, to connect the load to the individual turns of the winding. Resistance characteristics, mechanical design, and thermal properties of the contact are most important for proper operation of the transformer. A schematic drawing of the Variac together with a detailed view of the contact is

Figure 1. 170-volt-ampere Variac transformer assembled for back-of-panel mounting

Figure 2. An 860-volt-ampere Variac transformer for laboratory use

Figure 3. A five-kilovolt ampere Variac transformer

shown in Figure 4. The width of the contact is such that in sliding over the winding, one turn can be short-circuited but not two. The contact is represented as a block, connecting points 1 and 2 on successive turns of the winding to point 3 on the contact holder. The three-terminal block can be represented by an equivalent circuit of three resistors, R_1, R_2, R_3, between the points 1, 2, and 3 as shown in Figure 5. This equivalent circuit has been found useful in the following analysis of optimum contact design, but it should be understood that the contact resistance between a carbon brush and a metallic surface varies with the current passing through the surface and that the resistance of the carbon brush itself depends to a large degree on current density. Although the behavior of carbon brushes is not very well understood, they have been used for many purposes with great success for a long time and can be manufactured to close specifications. Experimental data show that the resistance of a carbon brush varies with the current passing through it in a way to maintain a substantially constant voltage drop. This voltage drop varies with the composition of the carbon and with the pressure applied and is used by brush manufacturers in the rating of their product. A typical current-voltage characteristic of a carbon brush is shown in Figure 6. It is reasonable to expect that a definite relation between this voltage drop and the voltage-per-turn of the Variac transformer has to be maintained to prevent excessive heating of the short-circuited turn and of the contact.

To show this relation, it is convenient to use the equivalent circuit shown in Figure 5. It can be seen that resistance R_3 is not included in the circuit of the short-circuited turn. Since it does not serve any useful purpose, it can be reduced to a small value by proper design of the contact holder and could be considered as part of the load resistance R_3.

The resistance of one turn of the winding, R_4 is made as low as possible in accordance with transformer design practice. The resistances R_1 and R_2, therefore, have to be relied on to keep the circulating current in the short-circuited turn below a value that might damage the transformer or overheat the contact. This circulating current is shown as I_0 in Figure 5 and the load current as I_2. The voltage-per-turn between points 1 and 2 is e_0. To simplify the following analysis of optimum contact design, Figure 5 is drawn as a section of a two-circuit transformer rather than of an autotransformer, and the current in the winding preceding the short-circuited turn is the same as the load current. It is further assumed that the contact is symmetrically located with respect to the two points 1 and 2, but R_1 is not necessarily the same as R_2, since the current flowing through these two points will not be the same. In an autotransformer the current in the winding would be different from the load current, but the contact problem would be exactly the same.

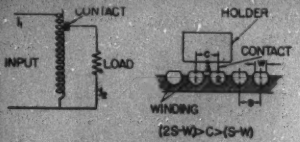


Figure 4. Schematic diagram of Variac transformer and contact

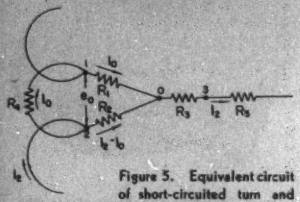


Figure 5. Equivalent circuit of short-circuited turn and contact

The problem of optimum contact design for a transformer of a given voltage-per-turn e_0 and given maximum load current I_2 is reduced to the problem now, of finding those values of R_1 and R_2 for which the energy loss is a minimum. It must be remembered, of course, that both R_1 and R_2 are the equivalent resistances of a single piece of carbon material and that they cannot be chosen independently of each other. The obvious suggestion, therefore, of making R_1 zero and R_2 infinite cannot be realized in a Variac transformer. It is a perfectly good solution and is used in tap-changing transformers of conventional design.

The energy loss in the two resistances according to Figure 2 is

$$W = R_1 I_0^2 + R_2 (I_2 - I_0)^2 \qquad (1)$$

and since

$$R_1 I_0 = R_2 (I_2 - I_0) + e_0 \qquad (2)$$

$$W = \frac{e_0^2}{R_1 + R_2} + I_2^2 \frac{R_1 R_2}{R_1 + R_2} \qquad (3)$$

The first term is seen to be the dissipation due to the voltage between adjacent turns acting across the two brush resistances in series. The second term is due to the load current flowing through the two resistances in parallel. The resistances R_1 and R_2 correspond to the currents I_0 and $I_2 - I_0$. If these resistances were constant and independent of current, the first term would be the no-load brush dissipation. If the ratio of the two resistances is called n^2

$$R_2 = n^2 R_1 \qquad (4)$$

and substitution of equation 4 in equation 3 yields

$$W = \frac{e_0^2}{(1+n^2)R_1} + I_2^2 R_1 \frac{n^2}{1+n^2} \qquad (5)$$

Setting the derivative of W with respect to R_1 in equation 5 to zero, the value of R_1 is obtained for which the contact loss is a minimum.

$$R_1 = \frac{e_0}{I_{2n}} \qquad (6)$$

The combination of equations 4 and 6 gives a resistance value R_0 which might be called the optimum contact resistance.

$$R_0 = \sqrt{R_1 R_2} = \frac{e_0}{I_2} \qquad (7)$$

If the two brush resistances are equal, they should have the value R_0 for minimum total loss. If they are unequal, their geometric mean should have that value.

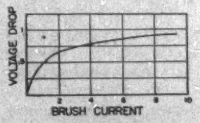


Figure 6. Current–voltage characteristic of a carbon contact

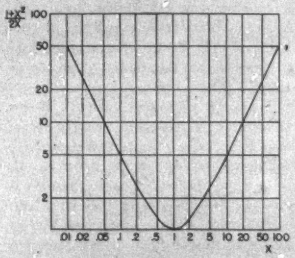


Figure 7. Plot of a function similar to that used in equation 11

To find out how much the contact loss is increased if the geometric mean of the two resistances deviates from R_0, a second parameter k is introduced

$$\sqrt{R_1 R_2} = n R_1 = k \frac{e_0}{I_2} \qquad (8)$$

and by substituting equation 8 in equation 5, the energy loss is found to be

$$W = e_0 I_2 \frac{n}{1+n^2} \cdot \frac{1+k^2}{k} \qquad (9)$$

If the two resistances R_1 and R_2 are equal and have the optimum value, both n and k are 1 and the energy loss may be called W_0.

$$W_0 = e_0 I_2 \qquad (10)$$

It follows that in the general case, if R_1 and R_2 have arbitrary values

$$W = W_0 \frac{2n}{1+n^2} \cdot \frac{1+k^2}{2k} \qquad (11)$$

Figure 7 shows the plot of a function similar to that used in equation 11 and it can be seen that the energy loss is increased by 25 per cent, for instance, if the geometric mean of the two brush resistances is double or is one-half of the optimum value, and that this increase of loss can be compensated by making one of the resistances four times as large as the other. It is apparent that to reduce the energy loss considerably below W_0, very high ratios of brush resistance values are required. The two factors in equation 11 tend to offset each other and consequently the geometric mean resistance must be held closely to the correct value.

Returning now again to Figure 5, it can be deduced without any computation that the energy loss $W_0 = e_0 I_2$ is obtained, if the voltage across R_1 equals e_0. In that case, the voltage across R_2 is zero. The full-load current I_2 flows through R_1 and the current in the short-circuited turn equals the load current. This condition is expressed by

$$I_0 = I_2 \qquad (12)$$

$$R_1 I_2 = e_0 \qquad (13)$$

Substituting equation 13 in equation 3, it is seen that

$$W = e_0 I_2 \qquad (14)$$

independent of R_2.

That a relation of this kind between the voltage per turn of a Variac transformer and the voltage drop in the contact would have to be maintained was suggested at the beginning of this analysis. It is apparent now that if the voltage drop in the contact equals the voltage per turn, the contact resistance is the optimum value according to equation 7, and the contact loss equals load current times voltage per turn.

Although it is possible, according to equation 11, further to decrease the contact loss if the two contact resistances R_1 and R_2 could be chosen at will, and could be maintained in the proper relation as the contact moves from one turn to the other, it has been found in practice that materials with the required characteristic are not available. As a matter of fact, it is often difficult to find a material that will fit the simple relation of equation 13 where resistance or voltage drop is specified for a single value of current.

If the maximum load current of a particular transformer is used to determine the optimum contact resistance in accordance with equation 13, the contact loss will be smaller than W from equation 14 for any other load current, and will be less than one-half this value for no-load condition. Under no load the short-circuit

current must flow through R_1 and R_2 in series, and each one will be larger than R_1 from equation 13. This follows from the current-voltage characteristic of the material used, which will always have the general shape shown in Figure 6. The no-load short-circuit current, therefore, will be less than one-half the maximum load current.

It has been shown in the preceding paragraphs that the contact loss is proportional to the load current and to the voltage-per-turn. If the voltage-per-turn were increased, as is usual in larger transformers, the contact loss would rise rapidly and would soon present a serious problem. Decreasing the number of turns below a definite value is undesirable for another reason. If a 200-turn Variac is adjusted for 50 per cent output voltage for instance, the voltage-per-turn at that particular point is 1 per cent of output voltage, but in a 100-turn Variac at 10 per cent output voltage, it is 10 per cent. It is true that the resistance of the Variac contact helps to smooth out the steps between turns, but it has been found in practice that 100 to 200 turns should be used, even in large transformers, to maintain smooth control at low output voltages.

At 100 turns the contact loss of a Variac transformer is 1 per cent of output power, according to equation 14. Iron and copper losses of the same transformer might be an additional 3 per cent. If operation of the transformer at rated output produces the maximum allowable temperature rise of winding and core, about an additional one third of the winding and core surface is needed to take care of the contact loss. The contact loss is concentrated in the small contact block and good heat conduction between the contact block and the cooling surface is required. The cooling surface is called the radiator.

Contact Design

Actual design of contact and radiator are closely dependent on the design of core and winding, but the basic requirements can be stated independently.

The active surface of the contact should be as large as possible to reduce current density and to spread the inevitable contact loss over the largest possible area. The width of the contact, shown as C in Figure 4, is usually very small, since it is determined by the cross section of the turns. The other dimension of the contact surface is related to the cross section of the core and depends on the length of turn available in the plane that has been chosen for operation of the contact. Figure 8 shows three different core cross sections. Core "A" would be best for a contact operating on top, and core "C" for a contact on the circumference. Small transformers ordinarily have banked windings. A core of shape "A," for instance, would be made with the outside diameter three times as large as the inside diameter. The winding would be applied to form a single closely spaced layer of turns on the outside, and the turns would pile up in three layers on the inside. The top surface, then, would not be available for operation of the contact, except at the outside edge.

Carbon brushes used on rotating machines are subjected to considerable wear and are made long, to avoid frequent replacements. Variac contacts show very little wear and are made as short as possible, to reduce losses and to afford better heat conduction into the radiator. In laboratory tests, contacts show extremely small wear in continuous operation. The wear seems to be independent of load, and is about 0.02 inch in one million adjustment cycles. In actual use, contacts wear more rapidly than this figure would indicate, and it appears that resistance to wear is decreased if the contact is allowed to rest under load in the same position for long periods of time. In any case, Variac brushes do not "wear in" after a few days of operation like brushes of rotating machines. Their performance can, therefore, be made more uniform and more reliable if they are subdivided into several independent units. Large Variacs are built with six or more contacts operating in parallel, but on small transformers, this added complication is not always justified.

Since Variac brushes do not wear in, current density and specific pressure vary within wide limits, and can hardly be compared with the values recommended by carbon manufacturers. Current carrying capacity and pressure of a given contact are best determined in statistical tests on the winding surface of the transformer.

As an example, a 115 volt 5 kva transformer with 160 turns uses six contacts in parallel, each one carrying from five to ten amperes and having a spring pressure of about ten ounces. The dimensions of each one of the six blocks are approximately one quarter inch by one quarter inch by one quarter inch. These small carbon blocks are permanently fastened by soldering, or by pressure fit, into larger contact holders and form together with them six complete brushes. The brushes, in turn, are inserted into six slots of the radiator, and are pressed against the winding by springs. A schematic view of a six-brush contact is shown in Figure 9. The advantage of this brush construction, compared to the large carbon blocks used in motors and generators, is improved heat conduction to the radiator. As a result, the temperature of the contact surface can be kept at a lower value, and damage of the winding insulation is prevented. The radiator absorbs the heat of the contact primarily by conduction and transmits it to the surrounding air by radiation and convection. The material of the radiator is chosen for good heat conduction. Size and surface treatment determine radiation. Convection currents depend on general shape and are improved by ventilating channels.

To prevent the metal contact holders from short-circuiting the winding, if a carbon contact block should wear or break by accident, the travel of the brushes within the radiator slots is limited. Electrical connections to the brushes are made by flexible leads.

Figure 8. Cross section of cores

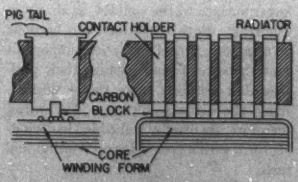


Figure 9. Six-brush contact operating on top of transformer

Contacts for Low-Power Transformers

The discussion of contacts, so far, has been mostly concerned with large transformers where contact losses must be reduced to a minimum. If contact losses rise rapidly with output power, it is equally true that they decrease on small transformers. On a 200-volt-ampere Variac transformer, for instance, with 500 turns, wound on a three inch-diameter core, contact losses according to equation 14 are 0.4 watt. This small power does not present any particular problem but the width of the contact would have to be under 0.025 inch to make it impossible to short-circuit more than one turn at a time. A carbon contact of that size would not be strong enough, but since the contact loss is low, no harm is done by

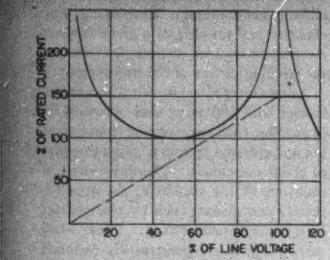


Figure 10. Output current for constant copper loss

increasing the width of the contact and letting it short-circuit several turns at a time. The transformer mentioned above actually uses a round contact of 0.09 inch diameter. It appears that six wires could be touched by a contact of this size, but because of the round shape, only three turns are effectively short-circuited and the contact loss is increased to 1.2 watts. It can be said in general that contact design need not follow the procedure outlined in the two preceding paragraphs unless it is desirable to limit contact losses to the inevitable minimum.

Winding and Core

A Variac transformer differs very markedly from a conventional transformer of equal rating. This is mainly due to four requirements discussed in detail in the preceding paragraphs: (1) the core is toroidally shaped, (2) the winding has to be applied to form a single layer at the contact surface, (3) the number of turns cannot be chosen for best efficiency or economy alone, and (4) the contact loss has to be added to the losses in copper and iron. If these points are kept in mind, winding and core can be designed by applying standard practice. In the following paragraphs, therefore, only a few points will be mentioned that are characteristic of the Variac.

A single-layer winding on a toroidal core does not fill up the winding space, and it is obvious that the amount of copper used is out of proportion to the amount of iron. This is particularly true with round wires and small toroids where the outside diameter must be much larger than the inside diameter. It is possible, of course, to use wire with rectangular cross section and to use large toroids, but that cannot be done when a compact transformer of low output power is desired. Rectangular wire could be used to great advantage in large transformers, over two kva for instance, but so far, the mechanical problem of applying the winding over the toroid has not been solved.

The resistance of a single-layer winding of round wire increases with the third power of the number of turns, and it follows, that the power rating of a toroidal core depends upon the voltage applied. For this reason Variac transformers cannot be built economically for high voltages.

The rating of a conventional transformer core increases rapidly with the frequency applied, since the number of turns can be decreased. In a Variac transformer, the number of turns is determined by the voltage applied and the only benefit obtained at increased frequencies is a reduction of core loss. However, if the cross section of the core is reduced at high frequencies, the gain is in the same proportion as in any transformer.

A laminated toroidally shaped core can be formed by two methods which are indicated in Figure 8. Core *A* is obtained by stacking ring-shaped laminations, core *B* by winding a long strip over a mandrel.[2] Losses in core *B* will be slightly lower than losses in core *A*, but both methods are equally satisfactory, and the choice depends mainly on the availability of materials and tools.

Application of a winding over a toroidal core requires special equipment, unless it is done by hand. Hand-winding, however, is not very practical, since small transformers have many hundreds of turns, and large transformers require wires that are too hard to handle. Toroid-winding machines[2] are ingeniously designed and apply single-layer or banked windings on large and small cores. They can handle a very wide range of wire sizes. It takes about 5 minutes to wind 500 turns of number 28 wire on a 3-inch-diameter core, and 25 minutes to wind 160 turns of number 8 wire on a 12-inch-diameter core.

The wire used is always insulated. A very high grade of insulation is required to stand the mechanical abuse during the process of winding, and to stand high temperatures in operation. At the contact surface, the insulation has to be removed. In addition, the wire is flattened to offer a larger surface to the contact, as shown in Figure 4. Both operations can be done on a grinding wheel. It is very important that the wires cannot change their position after grinding, since that would destroy the contact surface. The wires, therefore, are usually embedded in a winding form with a groove for each individual turn.

Mounting of the toroidal core, covered almost entirely by the winding, is another problem that requires serious consideration. Ordinarily, the winding covers 320 degrees and clamps cannot be used where they would interfere with the movement of the contact, or where they would form a short-circuited turn around the core. Permanent close alignment of the control shaft and the contact surface is very important, and high local pressure must be avoided on the winding.

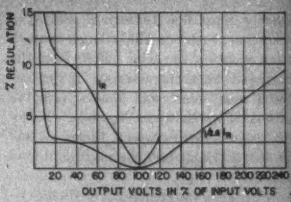


Figure 11. Regulation of transformer with 1.2 and 2.4 voltage step-up

Most Variac transformers are designed for air-cooling, but forced air draft and oil have been used in special applications to reduce size and weight to a minimum.

Rating and Taps

In the discussion of contact loss the term "maximum load current" has been used. It was assumed that the transformer would reach the highest permitted temperature at this current, the largest current that the contact has to handle. This current, called the "rated current," is an important characteristic of the Variac transformer.

Figure 4 shows the most commonly used connection of a Variac transformer to line and load. If the output voltage into the load is changed by moving the contact, and the load current is held constant by changing the load resistance, the current in the different parts of the winding changes. Copper losses, except those due to magnetizing current in the winding, start at zero for zero output voltage, reach a maximum at one-half line voltage, are zero at line voltage, and increase rapidly from there on. Core and contact losses are independent of output voltage.

The point above line voltage, for which the losses equal again the losses at half line voltage, is found to be at 20 per cent above line voltage. For this reason the line voltage tap on Variac transformers is almost always at 83 per cent of the turns. At rated current, the temperature rise of the Variac transformer reaches the maximum value at two settings of output voltage: at one-half line voltage and at maximum. The rated current could be exceeded at all other points if it were not

limited by the contact. In Figure 10 load current in per cent of rated current, for constant copper loss, is plotted against output voltage, in per cent of line voltage. If the contact is designed for a "maximum current," 50 per cent over "rated current," load currents up to the heavy line in Figure 10 can be used. The dotted line is the voltage-current characteristic of a constant load that draws "maximum current" at line voltage. It can be seen that this straight line is always below the limiting curve, and it follows that the transformer would not overheat at any output voltage, under line-voltage, if connected to this load. Experience has shown that contacts can be designed to carry considerably more than rated current in small Variac transformers, but in large transformers, the contact surface is not always sufficient to allow an increase above rated current as high as 50 per cent. Variac transformers are, therefore, rated by the following terms: (1) rated current —the current that can be drawn at any position of the control shaft; (2) maximum current—the current that can be drawn at low output voltages and at voltages near input voltage; (3) load rating —the volt-amperes obtained by multiplying maximum current by line voltage.

Whenever output voltages above line voltage are not required, or when the load could be damaged by overvoltage, the line should not be connected to the tap of the transformer, but to the full winding. In other applications it may be desirable to obtain more than a 20 per cent increase of output voltage with respect to line voltage, and the input could be connected still further down on the winding. The voltage across the full winding cannot be increased, of course, since that would increase flux density and voltage-per-turn, but all Variac transformers designed for 230-volt lines are tapped for connection to 115-volt circuits. If power is supplied at rated current to the center tap of a transformer, the output current is one half of rated current. If power is supplied to a tap that will give a maximum output voltage of $2\times1.2=2.4$ times input voltage, the connection provided on 230-volt Variac transformers, the output current for which copper losses are not excessive is 1/2.6 of rated current.

Regulation

Regulation of a transformer can be expressed as a voltage drop under load, in per cent of output voltage. In a Variac transformer the voltage drop in the contact is added to the voltage drop in the winding, and since the contact drop at full load current always equals the voltage-per-turn, the regulation at low output voltages is considerably increased. On the tenth turn of a transformer, the regulation due to contact drop always must be 10 per cent under these conditions, but the actual voltage of the tenth turn decreases as the total number of turns is increased. In a 200-turn Variac, connected to give 20 per cent overvoltage, for instance, the voltage-per-turn is only 0.6 per cent of input voltage, and contact regulation is better than 10 per cent, down to output voltages as low as six per cent of line voltage.

Autotransformers have inherently better regulation than two-circuit transformers. The improvement is most noticeable if the output voltage is close to line voltage and regulation is so good that careful protection against short circuits in the load is important. On the other hand, the leakage reactance of a single-layer winding on a toroidal core is large compared to the leakage reactance of a conventional transformer where it can be minimized by proper design.

Over-all regulation of Variac transformers in their most useful range, near input voltage, can be considered excellent compared to other control devices, but it should be kept in mind that at low output voltages and at high ratios of voltage step-up, voltage drop under load cannot be disregarded. A typical regulation curve is shown in Figure 11, where voltage drop in per cent of output voltage is plotted against output voltage in per cent of input voltage. The upper curve applies for a Variac transformer with a maximum voltage step-up of 1.2 at rated current and the lower curve for a voltage step-up of 2.4 at 1/2.6 of rated current. The effect of contact drop can be clearly seen in these curves at low output voltage. The inversion of the curves at one third of input voltage is due to the fact that output power decreases at lower output voltages. A further discussion of regulation is beyond the scope of this paper, but it is interesting to note that for constant voltage-per-turn the regulation at rated current varies very little with the size of the transformer.

Special Transformers

The use of a carbon composition contact on the turns of a transformer winding is not limited to toroidal autotransformers. This particular application has been discussed in detail, since it combines many advantages, but it is obvious that the transformer core could have any desired shape and that it could carry any number of additional windings.

One important application of a Variac transformer with an additional winding is a voltage regulator with limited range, that can vary the output voltage from 100 to 130 volts, for instance, when connected to a 115-volt line, or maintain constant 115-volt output voltage if the line voltage varies from 90 to 120 volts.

In another application, line-voltage is connected to the contact of a multiple-winding transformer. Moving the contact changes the number of primary turns and varies simultaneously the output voltage of several windings.

For applications in multiple-phase circuits two or more Variac transformers are mounted together with their contacts controlled by a single shaft.

References

1. United States patent number 2,009,013, issued July 23, 1935.

2. Toroidal Winding Machines, F. E. Planer. *Journal of Scientific Instruments*, Institute of Physics, London, volume 20, December 1943, pages 185–90.

Prevention of Rotor-Winding Deformation on Turbogenerators

JOHN G. NOEST
MEMBER AIEE

Synopsis: During recent years there have occurred several cases of failures on turbogenerators which were found to be due to a singular type of deformation of the rotor windings. It is recognized that the deformation of rotor windings is due to forces set up in the windings by the interaction of centrifugal force and temperature change.[1]

The purpose of this paper is to discuss briefly the phenomena responsible for this type of deformation, and to show that by means of preheating of the rotor windings to a definite predeterminable winding temperature, the resulting mechanical stresses can be very materially reduced so that winding deformation is held to a minimum.

Cause of Rotor-Winding Deformation

THE phenomenon of rotor winding deformation on turbogenerator rotors is discussed in reference 1. As copies of this paper are not readily available, the subject is here briefly reviewed.

All large turbogenerator rotors are built with the rotor winding, consisting of a number of multiturn coils laid in milled radial slots with metal wedges supporting the coils against the radially directed centrifugal force. Asbestos and mica are the principal insulating materials. At the ends of the rotor body, the individual coils are supported against deformation by end rings, with insulating material bracing blocks. The mechanical strength that can be built into the bracing is limited by the mechanical strength of the insulating materials used for coil insulation.

Several cases of rotor winding failure have occurred that were found to be due to a peculiar type of deformation of the rotor coils. This deformation is the result of shortening of the rotor conductors within the rotor slots. The failures, involving electrical grounds and interturn short circuits, all occurred at points where the rotor windings leave the rotor body or in the portions of the coils located under the end bells of the rotor. Grounds developed by crushing of the coil insulation, whereas interturn short circuits were found to be caused by the crushing of the turn-to-turn insulation. In each of these cases the underlying cause was a deformation of the coils, in which the conductors nearest to the center of the rotor shaft had become shortened most, while conductors more remote from the rotor shaft showed diminished shortening; the outermost conductors being found entirely unaffected. Blocking between coils was found either bent or broken, showing that the forces involved were high in order of magnitude. In some cases, the innermost conductors were found displaced from their original position by as much as the width of the conductors. These displaced conductors, under the influence of centrifugal force, were subjected to eccentric loading between conductors and the resulting high unit pressures on the turn-to-turn insulation ultimately produced structural failure of this insulation, causing turn-to-turn short circuits. Figures 1A, 1B, and 1C illustrate the conditions.

The basic cause of rotor-winding deformation may be explained if the processes of starting, loading, and shutting down of the turbogenerator are examined in detail. The turbogenerator, having cooled during a preceding outage to approximately ambient temperature, is started via the turbine and is driven at low speed for a period varying from one half to two hours, depending on the size of the unit involved and on the temperature the turbine has cooled to. Near the end of the turbine "warming up" period, the generator speed is rapidly increased to synchronous speed and, after applying field excitation, the generator is synchronized to the bus and loaded. The significant point of this starting procedure is that field current is not applied to the rotor winding until after nearly all of the centrifugal force is established by the rotational speed and the conductors are locked in position as a result. The rotor winding is therefore not subjected to a temperature rise until after the full effect of centrifugal force is established. After the field current is applied and as the generator is loaded, the rotor winding resistance loss appears as heat in the rotor conductors. As the temperature of the conductors increases a portion of this heat, proportional to the time rate of temperature rise, is stored in the thermal capacitance of the conductors and the remainder is transferred by conduction through the coil insulation to the rotor body at a rate proportional to the instantaneous temperature difference between the rotor winding and the rotor body. This process of combined heat storage and heat dissipation by conduction, results in an exponential approach to an ultimate temperature and involves a thermal time constant (Appendix IV). As the total weight, and with it the thermal mass, of the rotor winding is small, the thermal time constant of rotor-winding temperature rise over the rotor-body temperature is small. As heat is transferred to the rotor body, it experiences a temperature rise over the surrounding air. During increasing rotor-body temperature a portion of the heat transferred to it from the rotor winding is again stored (proportional to the rate of temperature rise) and the remainder is transferred to the surrounding air-gap air by forced convection at a rate proportional to the temperature difference. Because of the great weight of the rotor body, its thermal time constant is large (Appendix IV). With suddenly applied and thereafter constant field current the process of heat dissipation from the rotor winding is summarized as follows: The temperature rise of the rotor body over air-gap air (or approximately ambient air) reaches its final value slowly. After the initial fast temperature rise of the rotor winding, the winding continues to increase in temperature as the rotor body heats, finally maintaining, for constant field current, a constant differential.

While these temperature changes occur, the rotor conductors are under the influence of centrifugal force which tends to force them radially outward. Each rotor-conductor's centrifugal force is a function of its radial location and angular velocity. The centrifugal force of the innermost conductor is imposed on the next conductor, whose own centrifugal force adds to that of the first conductor, imposing the total on the third conductor and so on, until the wedge supports the accumulated centrifugal force of all conductors in the coil. Figure 2 shows a typical curve for a large rotor, giving centrifugal forces in terms of conductor location.

Any tendency of the coil as a whole, or of any conductor in the coil, to move in an axial direction is opposed by the frictional resistance created by the centrifugal force. The magnitude of the coefficient of friction is somewhat uncertain but probably

Paper 44-85, recommended by the AIEE committees on electrical machinery and power generation for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944, and the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944. Manuscript submitted February 14, 1944; made available for printing March 21, 1944.

JOHN G. NOEST is assistant engineer, electrical engineering department, Consolidated Edison Company of New York, Inc., New York, N. Y.

lies between 0.1 and 0.3. Even with the lower value and with values of centrifugal force as given in Figure 2, it is obvious that large portions of the slot lengths of the rotor conductor are firmly locked on each other and on to the wedge.

However, as the rotor conductors are being heated they tend to expand against the frictional forces which hold them locked in place. When the conductor-temperature rise is low, the tendency of the conductors to expand results in the creation of compressive stresses in the conductor within the elastic limit of the conductor material. With increasing rotor-body temperature, additional stress is produced on account of the differences in the coefficients of linear expansion of rotor conductor and rotor body, which at some critical temperature rise produce total stresses in the rotor conductor in excess of the elastic limit, and result thereafter in permanent plastic deformation. When the generator's load is reduced, the temperature of the rotor winding decreases, and the initial stress, which is held in elastic deformation, is released. When the generator is shut down, cooling takes place without the restraint of centrifugal force and the rotor conductors are free to contract as they cool. The plastic strain which was initially established at the high temperatures is retained, leaving the so-strained conductors permanently shortened. Repetition of this cycle of starting, loading, and shutting down at sufficiently high temperature rises results in continuing deformation in spite of the hardening effect of the cyclic plastic working of the conductor material. At some lower temperature rises however, deformation may cease after a small number of cycles because of the hardening effect of plastic working during the first few cycles.

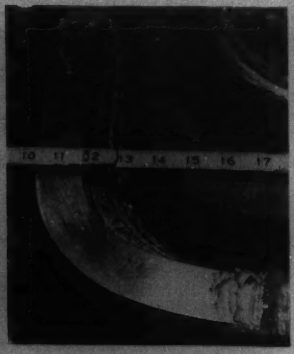


Figure 1A. Rotor-winding distortion, 160,000-kva 1,500-rpm generator

The preceding analysis gives a satisfactory qualitative exposition of the phenomenon of winding deformation for which a quantitative verification is more complex. The added complexity comes from the fact that in the discussion of conductor temperature an assumption of equal temperature for all conductors of a coil is really inadmissible. The temperature of the conductors of a coil is lowest for the outermost conductor, it rises to a maximum somewhere in the interior of the coil, and drops again toward the innermost conductor. Figure 3 shows a relation of conductor location and temperature rise, calculated by means of an equivalent electrical network for a rotor coil of a large generator neglecting all heat flow in the axial direction. Based on the temperature rise distribution of Figure 3, on an idealized stress-strain curve, as shown in Figure 4, and in consideration of the effects of varying centrifugal force with conductor location, the deformation for a single cycle, Figure 5, was calculated. Comparing calculated deformation (solid line in Figure 5, with the measured deformation on the generator rotor shown in Figure 1A (dashed line in Figure 5) good agreement may be observed to exist for all conductors excepting the two innermost ones. Similarly, calculated curves, shown as Figure 8 in reference 1, show a like tendency toward decreasing deformation for the innermost conductors. It appears, therefore, that in addition to the previously discussed factors, there must be others in order to account for the remaining discrepancy between calculated and observed conditions. One of these factors is probably buckling of the innermost conductors in whatever space there may exist at the bottom of the slot. The force required to buckle a conductor as a column may be expected to be relatively small since a conductor, as a column, is a very weak one indeed, even if the radial bracing by centrifugal force is taken into account.

Figure 1B. Rotor-winding distortion, 21,000-kva 1,500-rpm generator

Prevention of Rotor-Winding Deformation By Preheating

In the preceding section it was shown that the rotor-winding deformation is caused by the temperature change which occurs after the rotor conductors are prevented from free expansion by the locking action of centrifugal force. It was shown that when the temperature changes are sufficiently small, deformation is small and moreover may be expected to cease entirely after a limited number of cycles. The prevention of excessive rotor-winding deformation, therefore, lies in the reduction of the magnitude of temperature variations. The permissible magnitude of temperature variation is a function of the mechanical properties of the conductor material and the generator designer has control of both the magnitude of temperature variation and the conductor material used. However, the operator gains control of one of the factors involving the magnitude of stress developed in the conductor, when he is enabled to fix the initial temperature from which all subsequent temperature changes take place. By preheating the rotor winding and body with the body revolving at very low speed the expansion of the conductors and rotor body, as the temperature rises from ambient to preheat temperature, takes place free from frictional restraint produced by centrifugal force. Subsequent temperature variations due to generator load changes at synchronous speed then produce stresses

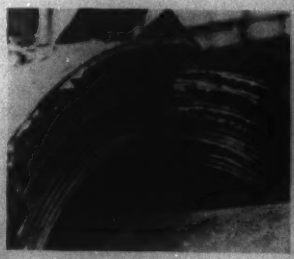


Figure 1C. Rotor-winding distortion caused by overloading 50,000-kva 50-cycle generator

which are proportional to the difference between actual and preheat temperature instead of the difference between actual and ambient temperature. Furthermore, the initial or preheat temperature can be chosen in such a manner that the stress in the conductor material becomes a tensile stress at light loads and the compressive stress which would result in creep in compression at high loads is nullified by the creep in tension at light loads. That initial or preheat winding temperature which produces a minimum of permanent winding deformation for a given rotor during the expected operating cycle is the optimum preheat temperature for the given generator.

As the expansion of the rotor body is also a factor contributing to the total stress in the winding conductors, there is also an optimum preheat temperature for the rotor body, which, together with the optimum winding preheat temperature, assures lowest possible deformation. As the rotor winding temperature and the rotor body temperature differ by the temperature rise of the winding over the rotor body, it is to be expected that the two optimum temperatures, that of the rotor body and that of the rotor winding, will be found to differ. This situation points to preheating with current in the rotor winding as the best method and knowing the difference between the two optimum temperatures permits the determination of the required current.

In the determination of the optimum preheat temperatures two criteria exist, namely, minimum stress and minimum deformation. The two are not synonymous, since the latter is not only a function of stress but of the duration of stress as well. An example of a calculation for a preheat procedure is given in Appendix II of this paper in which equations having the criteria of minimum deformation, developed in Appendix III are used. The development of the equations of Appendix III are based upon an assumed behavior of copper under mechanical stress which is believed to be approximate to the actual behavior of copper in the temperature range and stress range as here applied, with sufficient accuracy for the purpose. Because of the necessary approximation it is desirable to test the result of calculation made with the method of Appendix III, by calculating expected extreme stresses as is done in the example of Appendix II. For most load cycles, the method of Appendix III will give tolerable values of stress. In the author's opinion tolerable values of stress for windings of soft annealed copper are in the order of those calculated in Appendix II, and should not exceed 5,000 pounds per square inch.

The refinement that can reasonably be incorporated in a preheating procedure is limited by practical considerations, of which a primary one is the accuracy with which rotor-winding and rotor-body temperatures can be determined. Experience shows that this accuracy is not likely to be greater than plus or minus five degrees centigrade. The assumptions in regard to the behavior of the conductor material, made in Appendix III must be viewed in this light, and when so viewed they become more acceptable.

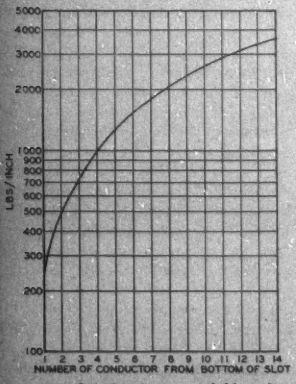


Figure 2. Centrifugal force on field-winding conductors at rated speed

Practical Aspects of Preheating

In the practical application of preheating of turbogenerator rotors, there are a number of factors, aside from those previously discussed, that must be considered if a workable procedure is to be obtained. Among these are:

(*a*). The arrangement of existing cooling system, that is, whether the generator is equipped with shaft driven blowers or with separately driven blowers, and whether the generator cooling system is a closed or open system.

(*b*). What means are available to furnish the required preheating current.

(*c*). There is the problem of co-ordinating the preheating procedure with the starting procedure of the turbine.

In regard to the existing cooling system, the preceding discussions show that it is desirable to obtain by means of preheating a certain definite rotor-winding temperature and also a temperature distribution throughout the winding as near as possible to that existing when the generator is in operation and carrying load. This requirement can be approached only if preheating is carried out with as near as possible normal air flow through the generator; however, it cannot be reached completely since preheating must be performed with the rotor revolving at low speed. On generators equipped with shaft-driven blowers, the requirements of nearly normal ventilation and low generator speed, of course, cannot be met simultaneously. In this case it may be necessary to use a procedure in which preheating is carried out in steps. This is accomplished by starting the preheat at relatively high rotor speeds in order to provide the required ventilation and then at one or more intermediate temperatures reducing the speed, the steps being so timed as to prevent excessive winding stresses. With each step of speed reduction the accumulated stresses are released until, at the point where the specified preheating temperature is reached, a final slowing down releases all stresses before the generator is again accelerated and synchronized. On generators equipped with separate blowers, this difficulty is not likely to appear.

The nature of the cooling system is a factor in the preheating procedure because of the necessity to measure the rotor body temperature indirectly, that is, in terms of the winding temperature. This involves the thermal time constant of the rotor-winding-temperature rise over the rotor-body temperature. In view of the relative smallness of this time constant, it is convenient to eliminate it as a factor by holding the preheating current constant at that value which produces the expected rotor-winding-over-rotor-body temperature rise. However, with constant preheating current, the control of temperature lies in the adjustment of the cooling

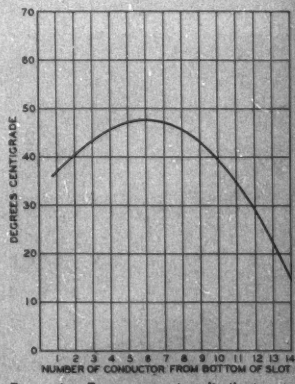


Figure 3. Temperature rise distribution in field coil

system. This is an easy matter on generators having a closed cooling system in which case the water flow through the coolers can be regulated. Where a generator operates on an open ventilating system the considerations of the preceding paragraphs in regard to temperature distribution within the rotor winding may have to be compromised because of the necessity of controlling the winding temperature by changes in turbine speed. Variations in the preheating current for the control of rotor-winding temperature should be resorted to only after all other means of controlling temperature are exhausted, since the attainment of the optimum rotor winding—rotor body temperature rise then becomes very difficult.

In regard to the availability of direct current for preheating, several additional factors enter into consideration. When a motor-driven or turbine-driven d-c variable-voltage generator of sufficient capacity is available, the problem is simple. Where the preheating current must be taken from a constant-voltage d-c source and where a field rheostat in the rotor circuit exists, the problem is equally simple. When neither exists, preheating can be carried on in steps at generator speeds sufficiently high to permit the use of the shaft exciter as power source. In the latter case, it may be found expedient to provide space heaters in the generator for the purpose of holding the generator at some elevated temperature from which preheating can be carried out in one step. Finally, the objective of preheating can be approached in some cases to a sufficient extent by the use of space heaters alone. The latter two methods may be satisfactorily applied in those cases where generators are taken off the line only infrequently so that higher stresses and larger values of deformation per cycle become acceptable.

The problem of co-ordinating a particular preheating procedure with the turbine starting operations contains so many factors in addition to those previously discussed, that an attempt to generalize is practically of no value.

Experience With Preheating

Preheating of rotor windings has been adopted for five generators on the system of the Consolidated Edison Company of New York, Inc., and the experience at the time of preparation of this paper extends over a period of approximately six months. The generators involved are turbogenerators of the following sizes: two generators, 200,000 kva, 60 cycles, 0.8 power factor, 1,800 rpm; one generator, 160,000 kva

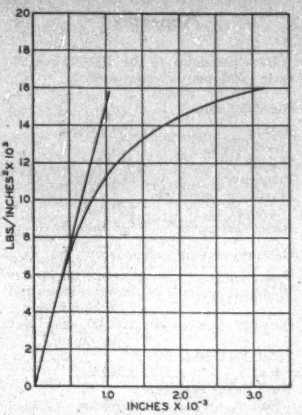


Figure 4. Stress–strain curve for soft annealed copper

25 cycles, 1.0 power factor, 1,500 rpm; and two generators, 60,000 kva, 25 cycles, 1.0 power factor, 1,500 rpm. Appendix I gives detailed data for the 160,000-kva, 25-cycle generator to which the example of Appendix II applies.

All these generators are equipped with external motor- or turbine-driven blowers, with closed cooling systems using air coolers, with shaft rotating gear and with field rheostats in the rotor circuit. Aside from differences in specified preheating currents and temperatures, the preheating procedures for all of these generators are substantially the same. Subsequent discussion will, therefore, be confined to the 160,000-kva 25-cycle unit.

The turbine starting operation and preheating procedure are carried out as follows:

1. Depending upon the duration of the preceding outage of the turbogenerator, that is, upon the initial temperature of the generator rotor, the time required for preheating is varied from one to two and one half hours. Generally, the "warming up" time of the turbine varies similarly, but it is possible to start preheating with the generator on the shaft rotating gear by means of which the shaft is rotated at approximately two revolutions per minute. Application of the preheating current is not permitted at standstill in order to avoid burning of the collector rings.

2. With the generator rotated by the turbine, not faster than 300 rpm, or with the generator on the rotating gear, the preheating current of 680 amperes (84 per cent of rated current) is applied to the rotor winding. Both generator cooling fans are started and provide practically normal air flow through the generator.

3. When the rotor winding approaches the specified preheat temperature, cooling water is admitted to control the temperature. The preheating current is held unchanged at a constant value. The preheat rotor-winding temperature is specified in relation to the prevailing cooling-water temperature as follows:

Cooling Water Temperature (Deg F)	Preheat Winding Temperature (Deg C)
Up to 45	65
46 to 60	73
61 and over	81

4. When the specified preheat temperature is reached and when the turbine is sufficiently warmed up, the generator is shut down to standstill and immediately restarted. This is done to permit complete relief of all stresses that may have accumulated in the winding. The preheating current still remains unchanged.

5. The turbine is now rapidly accelerated. As the speed increases above 1,000 rpm the operator reduces the preheating current just enough to prevent excessive generator voltage. When the generator reaches synchronizing speed the preheating current is removed, the shaft exciter is quickly switched to supply normal excitation, the generator is synchronized, and then loaded.

During the shutting-down period the cooling-water flow through the air coolers is reduced as the load is decreased to prevent excessive cooling, thus shortening the time required for subsequent preheating.

Calculations in Appendix II show that by using the above preheating procedure the stresses in the winding are 4,510 pounds per square inch in compression at maximum load and 3,790 pounds per square inch in tension at minimum load. Without preheating and starting at room temperature, the winding stresses would become 10,980 pounds per square inch in compression. It is expected that no

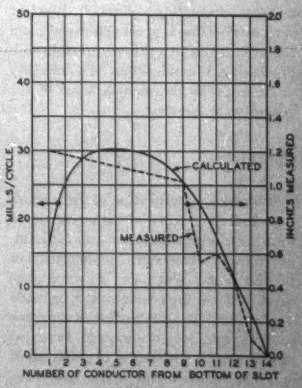


Figure 5. Measured and calculated deformation of a field coil

noticeable winding deformation will occur with the adopted preheating procedure.

The preceding example is an ideal one since facilities exist which permit the control of all of the diverse factors. Where such facilities do not exist, a great deal can still be gained by preheating in a less complete manner. So long as the rotor is brought to within its operating temperature range a material reduction in deformation can be expected.

Overloading of Generators

Frequently, particularly under the pressure of the present emergency, the problem arises whether a given generator can be overloaded with currents in excess of the rated field current and armature current. This problem becomes particularly pressing where a generator has a rated load temperature rise below that permissible by existing AIEE Standards. Very often this problem arises from the necessity to carry lower-power-factor loads and less often it arises from the availability of additional capacity in the turbine.

When temperature rise is less than the permissible at rated load it must not be assumed that the manufacturer had miscalculated in the design of the generator and in that way had really provided a generator larger than required. A safer assumption is that the manufacturer in designing the given generator was forced to compromise conflicting requirements with the result of having to design for a lower temperature rise in order to meet some other more pressing limitation. Among these limitations may well be that of field-winding deformation and if this be the major limitation, it may be possible to permit an appreciable increase in field current if preheating is adopted. Whether such overloading is at all permissible, and the extent to which it is permissible with preheating, is a subject to be thoroughly discussed with the manufacturer of the generator in question.

Conclusion

By means of preheating of rotor windings and rotor body of turbogenerators, rotor winding deformation can be minimized, with a consequent prolongation of the life of such windings. In some cases overloading of the generator can be made a safe procedure if preheating of the rotor windings and body is adopted. Practical procedures for preheating of rotor windings have been found to be easily coordinated with turbine-starting operations.

Appendix I

Data pertaining to the 160,000-kva 25-cycle 1,500-rpm turbogenerator.

Generator data:

Rating	160,000 kva
Power factor	1.0
Voltage	11.4 kv
Frequency	25 cycles
Maximum excitation voltage	250 volts
Rated field current	815 amperes

Generator-cooling-system data:

Type	Surface air coolers
Blowers	Separate motor and turbine driven
Quantity of cooling air	160,000 cubic feet per minute
Total heat loss, full load	2,245 kw
Total heat loss, no load	1,595 kw
Heat loss in rotor, full load	235 kw
Quantity of cooling water, maximum	1,000,000 pounds per hour
Maximum cooling water temperature	75 degrees Fahrenheit

Physical data:

Coefficient of linear expansion, copper—1.7×10^{-5} inch per inch per degree centigrade

Coefficient of linear expansion, steel—1.15×10^{-5} inch per inch per degree centigrade

Modulus of elasticity of copper—1.6×10^{7} pounds per square inch per inch

Generator operating data:

	Maximum Load	Minimum Load
Field current, amperes	875	460
Average rotor winding temperature, degrees centigrade	111.0	55.9
Average rotor body temperature, degrees centigrade	85.0	48.7
Airgap air average temperature, degrees centigrade	53.5	40.0
Air temperature into generator, degrees centigrade	40.0	30.4
Cooling water temperature, degrees Fahrenheit	75.0	75.0
Daily load cycle, hours	10*	12*

Appendix II

Example of calculation of the preheating procedure for a 160,000-kva 1.0-power-factor 25-cycle 1,500-rpm generator with data of Appendix I.

In the following all primed symbols refer to the minimum load condition and all double-primed symbols refer to the maximum load conditions and unprimed symbols refer to preheating conditions. All w subscripts refer to the rotor winding and all B subscripts refer to the rotor body.

* The remaining two hours are used in raising and lowering of load.

From Appendix I:

$T_w' = 55.9$ degrees centigrade
$t_w'' = 111.0$ degrees centigrade
$T_B' = 48.7$ degrees centigrade
$T_B'' = 85.0$ degrees centigrade
$t' = 12$ hours
$t'' = 10$ hours

Using equations 11 and 12 of Appendix III

$$T_w = \frac{t'T_w' + t''T_w''}{t' + t''} = \frac{(12\times55.9)+(10\times111)}{12+10} = 81 \text{ degrees centigrade}$$

$$T_B = \frac{t'T_B' + t''T_B''}{t' + t''} = \frac{(12\times48.7)+(10\times85)}{12+10} = 65.2 \text{ degrees centigrade}$$

The preheating current is then

$$I = I''\sqrt{\frac{T_w - T_B}{T_w'' - T_B''}} = 875\sqrt{\frac{81-65.2}{111-85}} = 681 \text{ amperes}$$

The resulting stresses in the copper are found as follows:

$$s_w'' = \alpha_w(T_w'' - T_w) = 1.7\times10^{-5}\times(111.0-81) = 51.0\times10^{-5}$$

$$s_B'' = \alpha_B(T_B'' - T_B) = 1.15\times10^{-5}\times(85-65.2) = 22.8\times10^{-5}$$

then

$$f'' = M(s_w'' - s_B'') = 1.6\times10^{7}\times(51.0-22.8)\times10^{-5} = 4{,}510 \text{ pounds per square inch}$$

This stress is produced in compression at the highest operating temperature. At the minimum load conditions:

$$s_w' = \alpha_w(T_w - T_w') = 1.7\times10^{-5}\times(81-55.9) = 42.7\times10^{-5}$$

$$s_B' = \alpha_B(T_B - T_B') = 1.15\times10^{-5}\times(65.2-48.7) = 19.0\times10^{-5}$$

$$f' = M(s_w' - s_B') = 1.6\times10^{7}(42.7-19.0)\times10^{-5} = 3{,}790 \text{ pounds per square inch}$$

This stress is in tension.

For comparison of the efficacy of preheating, the stress produced during starting from an ambient of 40 degrees centigrade to maximum operating temperature is calculated:

$$s_w = \alpha_w(T_w'' - 40) = 1.7\times10^{-5}(111-40) = 120.4\times10^{-5}$$

$$s_B = \alpha_B(T_B'' - 40) = 1.15\times10^{-5}(85-40) = 51.8\times10^{-5}$$

$$f'' = M(s_w - s_B) = 1.6\times10^{7}(120.-51.8)\times10^{-5} = 10{,}980 \text{ pounds per square inch}$$

Nomenclature:

α_w = coefficient of expansion for the winding
α_B = coefficient of expansion for the rotor body
s = strain
f = stress
M = modulus of elasticity

Appendix III

Nomenclature (for additional symbols see Appendix II):

T = temperature in degrees centigrade
a, k = constants
s, s_0 = plastic strains
u = creep rate
ϵ = base of the natural logarithm

Within the range of temperature and the range of stress occurring with preheating the creep rate is approximated by the following relation

$$u=\frac{ds}{dt}=af\phi(T) \tag{1}$$

where $\phi(T)$ is a function of the absolute temperature. For short-time creep rates very little is known about this function, although various attempts have been made[1] to approximate test results in long-time test. For this reason the function $\phi(T)$ is in the following analysis taken to be constant in the belief that this step will not greatly affect the result.

If an elementary length of conductor is stressed and then held so that its length remains invariant, the stress is relieved by creep according to the relation

$$-M\frac{ds}{dt}=\frac{df}{dt}=aMf \tag{2}$$

Setting

$$k=aM$$

for convenience,

$$-\frac{df}{dt}=kf \tag{3}$$

which has the solution

$$f=f_0\epsilon^{-kt} \tag{4}$$

where f_0 is the stress at the time $t=0$ Since

$$f_0=Ms_0 \tag{5}$$

and since

$$\begin{aligned} s_0''&=\alpha_w(T_w''-T_w)-\alpha_B(T_B''-T_B)\\ s_0'&=\alpha_w(T_w-T_w')-\alpha_B(T_B-T_B') \end{aligned} \tag{6}$$

The total strains accumulated during the times t'' and t' become

$$S_0''=[\alpha_w(T_w''-T_w)-\alpha_B(T_B''-T_B)]\times\int^{t''}\epsilon^{-kt}dt$$

$$S_0'=[\alpha_w(T_w-T_w')-\alpha_B(T_B-T_B')]\times\int^{t'}\epsilon^{-kt}dt \tag{7}$$

Integrating equations 7 and substituting the approximation

$$1-\epsilon^{-kt}=kt$$

$$\begin{aligned} S_0''&=[\alpha_w(T_w''-T_w)-\alpha_B(T_B''-T_B)]kt''\\ S_0'&=[\alpha_w(T_w-T_w')-\alpha_B(T_B-T_B')]kt' \end{aligned} \tag{8}$$

When the load cycle is complex equations 8 are used to determine T_w and T_B by trial and error. In most cases the load cycle is sufficiently approximated by calculation for maximum and minimum loads only. In the latter case equations 8 allow further analysis. Set

$$\begin{aligned} S_0''=S_0'=[\alpha_w(T_w''-T_w)-\alpha_B\times\\ (T_B''-T_B)]kt''=[\alpha_w(T_w-T_w')-\\ \alpha_B(T_B-T_B')]kt' \end{aligned} \tag{9}$$

Substituting in equation 9

$$r=\frac{\alpha_B}{\alpha_w}$$

and solving for T_w and t_B:

$$T_w-rT_B=\frac{t'T_w'+t''T_w''}{t'+t''}-r\frac{t'T_B'+t''T_B''}{t'+t''} \tag{10}$$

Since T_w and T_B in equation 10 are both unknown further, strict mathematical treatment is impossible. However, if

$$T_w=\frac{t'T_w'+t''T_w''}{t'+t''} \tag{11}$$

and if

$$T_B=\frac{t'T_B'+t''T_B''}{t'+t''} \tag{12}$$

are used, a satisfactory solution is obtained.

Appendix IV

When heating or cooling of a body, having thermal capacity, takes place in such a manner that the heat loss per unit time is directly proportional to temperature, the following relations apply.
Let

C = thermal capacitance in kilowatts per degree centigrade per hour
k = proportionality constant of heat dissipation in kilowatts per degree centigrade
H = heat loss in kilowatts
θ = temperature rise
T = time constant
t = time in hours

For heating

$$C\frac{d\theta}{dt}+k\theta=H \tag{13}$$

For cooling

$$C\frac{d\theta}{dt}+k\theta=0 \tag{14}$$

Equations 13 and 14 have the solutions

$$\theta=\theta_0\left(1-\epsilon^{-\frac{t}{T}}\right) \tag{15}$$

or

$$\theta=\theta_0\epsilon^{-\frac{t}{T}}\text{ respectively} \tag{16}$$

where

$$T=\frac{C}{k}$$

and where

θ_0 = ultimate temperature rise

For example, using values of Appendix I: For the rotor windings

$$C_w=\frac{C_1W_1}{3{,}413}=\frac{0.167\times20{,}000}{3{,}413}=0.974\text{ kilowatt per degree centigrade per hour}$$

For the rotor body

$$C_B=\frac{C_2W_2}{3{,}413}=\frac{0.212\times200{,}000}{3{,}413}=12.4\text{ kilowatts per degree centigrade per hour}$$

where

C_1 = specific heat of copper in kilowatt-hours per pound per degree centigrade
C_2 = specific heat of steel in kilowatt-hours per pound per degree centigrade
W_1 = weight of windings in pounds
W_2 = weight of rotor body in pounds

For the rotor winding

$$k_w=\frac{H}{\theta w_0}=\frac{235}{26}=9.04\text{ kilowatts per degree centigrade}$$

For the rotor body

$$k_B=\frac{H}{\theta s_0}=\frac{235}{31.5}=7.46\text{ kilowatts per degree centigrade}$$

Where θ_{w0} and θ_{s0} are the ultimate temperature rises of the rotor winding over the rotor body and of the rotor body over air-gap air, respectively.

$$T_w=\frac{C_w}{k_w}=\frac{0.974}{9.04}=0.1075\text{ hour}$$

$$T_B=\frac{C_B}{k_B}=\frac{12.4}{7.46}=1.67\text{ hours}$$

References

1. Deformation of Turbo-Alternator Rotor Windings, Due to Temperature Rise, G. A. Juhlien. *Journal* of the Institution of Electrical Engineers, London, England, volume 85, 1939, pages 544–52.

2. Creep and Relaxation of Oxygen-Free Copper, Evan A. Davies. *Journal of Applied Mechanics*, June 1943, pages A-101–5.

Blast-Tube Cooling for Aircraft Generators

CYRIL G. VEINOTT
MEMBER AIEE

Synopsis: Established principles of hydraulics are used to develop and explain fundamentals of blast-tube cooling. It is shown that the pressure-volume curves of a blast tube can be determined by flight tests, and that the pressure-volume curve of a generator can be determined in the laboratory. From the two pressure-volume curves, the air-flow through the generator in flight can be predicted, without *an actual flight test on the generator*. This procedure would save many flight tests, if pressure-volume curves of various blast tubes were available. It is shown that the pressure-volume curve of a blast tube can be determined by open-end and closed-end readings on the blast tube, and the complete curve can be expressed in terms of two constants readily determined from these readings. Once values of the constants are established, air-flow calculations become as simple as the application of Ohm's law. The theory also covers generators with an internal fan. A plea is made for accurate blast-tube data and for better specifications on blast cooling. A suggested form of blast-tube specification is given.

BLAST cooling has been a major factor in obtaining the phenomenal outputs of modern aircraft generators from a small weight of material. This subject, in spite of its importance, seems to have been neglected in technical literature and, as a result, the fundamental principles do not seem to be at all well understood. Because of this lack, the subject has often appeared to be more involved than it actually is. It is generally understood that the amount of air flowing through a given generator depends upon the pressure differential available across the generator, and it is also well understood that the amount of pressure available from the blast tube depends upon the amount of air drawn by the generator. Because of this mutual interdependence, flight tests are today generally taken with a specific generator and blast tube, and it seems to be generally felt that it is necessary to test each different combination of generator and blast tube. Just as Ohm's law enormously simplified the calculation of electric circuits, so can the calculation of blast cooling be simplified by the use of similar concepts, which will be defined, explained, and used in this paper. This line of attack clarifies the fundamental principles involved, makes it necessary to run only one series of tests on any given blast tube, and one series of tests on any one given generator. It is not necessary to test each and every combination of generator and blast tube. This line of attack also makes it possible to write specifications which simultaneously accomplish a number of purposes:

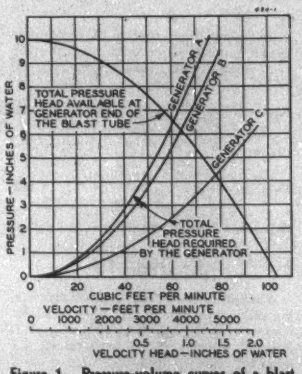

PRESSURE—INCHES OF WATER
TOTAL PRESSURE HEAD AVAILABLE AT GENERATOR END OF THE BLAST TUBE
GENERATOR A
GENERATOR B
GENERATOR C
TOTAL PRESSURE HEAD REQUIRED BY THE GENERATOR
CUBIC FEET PER MINUTE
VELOCITY—FEET PER MINUTE
VELOCITY HEAD—INCHES OF WATER

Figure 1. Pressure-volume curves of a blast tube and three representative aircraft generators

(*a*). The airframe builder has a definite specification which can be used not only to design the blast-tube installation, but also to test it. He need not be concerned with different generator designs.

(*b*). The generator builder has a definite specification that permits him enough latitude to design a generator for maximum effective use of the available air.

(*c*). The specification clearly indicates how much pressure should be applied to the generator in laboratory tests to *simulate flight* conditions. (This point should be of especial interest to a procuring agency.)

The scope of this paper is limited to a study of air flow; it is not directly concerned with heat transfer and rating.

Pressure-Volume Curve of a Blast Tube

Pressure and volume flow in a blast tube can both be measured by means of the familiar pitot tube and either a manometer or an air-speed indicator. Three kinds of pressure can be read: static head, velocity head, and total head, which is the sum of the other two. In this paper, all pressures, except atmospheric, are measured in inches of water. Total pressure is a measure of the total energy in the air stream, and velocity head, for a fixed density, is a measure of the volume of air flowing.

For purposes of illustration, assume a specific blast-tube installation in a plane which is flying at a constant indicated air speed, and further assume that the position of oil-cooler flaps, or any other air dampers that might affect the flow of generator cooling air, remains fixed. Let the total pressure at the generator end be measured with the end capped so that no air can flow. Now, let the end be partially uncapped so that some air can flow, and let the volume and total pressure at the end of the blast tube be measured. This reading can be repeated for a number of different volumes until the tube is wide open, and the total pressure is then only the velocity head at exit. If now, the total head is plotted against the number of cubic feet of air drawn per minute, a curve will result, probably of the form shown in Figure 1, which is a parabola. This curve has been established without using a generator and may be called the "pressure-volume" curve of the blast tube. While it has not been established experimentally that the curve is a true parabola, the science of hydraulics indicates that it probably approximates one.

Pressure-Volume Curve of a Generator

Experiment and theory alike demonstrate that the pressure-volume curve of a generator is substantially a simple parabola. Three such curves, determined experimentally, are shown in Figure 1. The curve for each generator shows, for example, the pressure required to force any given volume of air through it. The three points where the three curves intersect the pressure-volume curve of the blast tube show the respective pressures and volumes that will be obtained by each generator. Thus the pressure and volume that each generator would receive from this blast tube can be determined without actually testing each generator with this blast tube.

Paper 44-84, recommended by the AIEE committee on air transportation for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944. Manuscript submitted February 17, 1944; made available for printing March 13, 1944.

CYRIL G. VEINOTT is special development engineer, Westinghouse Electric and Manufacturing Company, Lima, Ohio.

The author acknowledges helpful comments and suggestions from H. J. Finison, Matériel Center, Wright Field, Dayton, Ohio, and from a number of his colleagues, including H. J. Braun, F. A. Heddleson, J. E. Mulheim, and G. G. Setterlund.

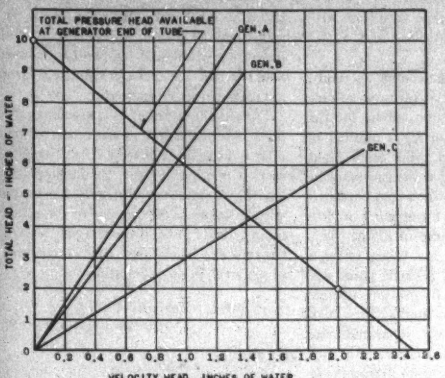
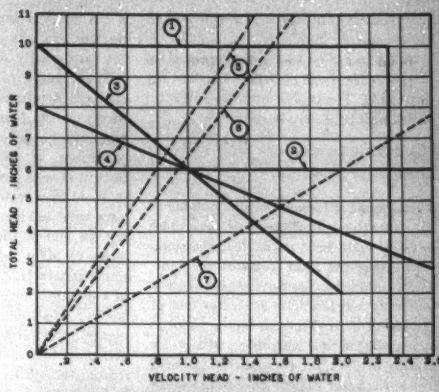

TOTAL PRESSURE HEAD AVAILABLE AT GENERATOR END OF TUBE
GEN. A
GEN. B
GEN. C
TOTAL HEAD - INCHES OF WATER
VELOCITY HEAD, INCHES OF WATER

Figure 2. Pressure-volume curves of Figure 1 replotted as a function of velocity head



1. PRESSURE-VOLUME CURVE PER SPEC. 95-32278 OF 3/3/42
2. PRESSURE-VOLUME CURVE PER SPEC. ANC-1-13, MAR. 43
3. PRESSURE-VOLUME CURVE PER SPEC. PROPOSED IN THIS PAPER
4. ALTERNATE PRESSURE-VOLUME CURVE PROPOSED
5. PRESSURE-VOLUME CURVE OF GENERATOR A
6. PRESSURE-VOLUME CURVE OF GENERATOR B
7. PRESSURE-VOLUME CURVE OF GENERATOR C

Figure 4 (right). A comparison of blast-tube specifications

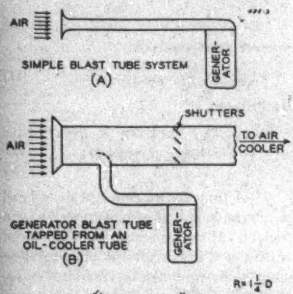


Figure 3. Blast-tube arrangements. Effect of shape of the entrance

The three generators for which the curves are shown are actual aircraft generators of different design which are in production use in aircraft today. None of them has an internal fan. The pressure-volume curve of the blast tube, necessary for purposes of illustration, was estimated since no experimental curve was available. However, the pressures shown for the three generators approximate the pressures which have been observed in flight. These curves show how unreliable it is to impress the same pressures upon different generators for comparative tests. For example, suppose six-inch total head is impressed upon all three generators for test. The volumes of air that would be received with six inch head applied are compared with the volumes received under flight conditions in the following table:

	Test	Flight
Generator *A*	58	61
Generator *B*	63	64
Generator *C*	93	78

Thus generator *C* would show 19 per cent higher temperature rise in flight than it would on laboratory test at six inches, although the tests on the other two generators would be approximately correct.

Table I. Tested Values of Air-Flow Resistance, R_g, for Three Different Designs of Aircraft Generators

(Based on a Two-Inch Blast Tube)

Conditions of Test	Generator A	Generator B	Generator C
Generator cold			
At standstill	6.51	5.90	2.80
At 2,500 rpm	6.82	5.71	2.87
At 3,500 rpm	6.94	6.04	2.90
At 4,000 rpm	7.15	6.19	2.91
After carrying 75 per cent load for one hour			
At 3,500 rpm	7.60	6.45	2.98

Alternative Method for Plotting Pressure-Volume Curves

In Figure 1, total pressure has been plotted as a function of volume. In Figure 2, the curves of Figure 1 are replotted with total pressure as a function of velocity head rather than volume. The pressure-volume curves become straight lines, which fact is an important advantage of this method of plotting. But much more important is the fact that, for all practical purposes, the curves of Figure 2 *are independent of air density, hence independent of altitude*, whereas the curves of Figure 1 are valid for only one air density. This statement is merely another way of stating the familiar principle of hydraulics that the lost head is proportional to the velocity head. Figure 1 could be valid for all altitudes, however, if the abscissae were understood to be "*indicated* cubic feet per minute," but the form of Figure 2 seems to be more convenient. Another advantage of using and plotting velocity head is that, when a pitot tube is used, *velocity head* is the quantity that is actually measured. Even if an air-speed indicator is used instead of a manometer, it is still velocity head which operates the instrument, though the scale is calibrated in miles per hour.

Calculation of Generator Pressures During Flight

In Figure 2, the pressure head across generator *A* and the velocity head (indicative of volume) of the air supplied was determined by finding the intersection of the pressure-volume curve of the blast tube with the pressure-volume curve of the generator, since the amount of head lost in the generator obviously has to be equal to that which is available from the blast tube. By using a concept of air-flow resistance, analogous to electrical resistance, this point of intersection can be calculated easily without plotting the curves of Figure 2. For any generator, the ratio

$$\frac{\text{head loss in generator}}{\text{velocity head at entrance}} = \frac{h_g}{h_v} = R_g \qquad (1)$$

is a constant, substantially independent of the pressure applied. This ratio R_g,

may be called the "air-flow resistance" of the generator. Similarly, the amount of head lost in a blast tube is proportional to the velocity head of the air flowing through it. Hence, the air-flow resistance of the blast tube may be defined as

$$\frac{\text{head lost in blast tube}}{\text{velocity head in blast tube}} = R_t \qquad (2)$$

The amount of pressure head available at the generator end of the blast tube must be equal to the head available at the scoop end, minus the head losses in the tube. The available head at the scoop end can be found by blocking the generator end of the blast tube and measuring the pressure h_c at the generator end, since, with no air flowing in the tube, there will be no head lost in the tube. Then, since the losses in the tube plus the losses in the generator must equal the available head, it follows from equations 1 and 2 that

$$h_c = h_v R_t + h_v R_g \qquad (3)$$

or

$$h_v = \frac{h_c}{R_t + R_g} \qquad (4)$$

The pressure across the generator is

$$h_g = h_v R_g = \frac{R_g}{R_t + R_g} \times h_c \qquad (5)$$

By way of illustration

For the blast tube of Figure 2

$h_c = 10.0$
$R_t = 4.0$

For generator B, $R_g = 6.45$
from equation 4

$$h_v = \frac{10}{4 + 6.45} = 0.958 \text{ inch}$$

and from equation 5

$$h_g = h_v R_g = 0.958 \times 6.45 = 6.16 \text{ inches}$$

which agrees with point of intersection shown in Figure 2.

Each blast-tube installation will have a different pressure-volume curve for each different indicated air speed of the plane. Likewise, if the generator blast tube is tapped off from a larger blast tube leading to an oil cooler, or intercooler, there will be a different pressure-volume curve for each position of the shutters in the main blast tube. Thus, the true performance of any given blast-tube installation can be represented by a family of pressure-volume curves, one for each significant flight condition. Each of these pressure-volume curves can be expressed, approximately at least, in terms of two significant constants, h_c and R_g. It is the author's opinion that, in any given installation, it is h_c which will show large variations with changes in flight conditions, and R_t will not vary greatly.

Flight studies of blast cooling should be made to determine the pressure-volume curves of the blast tube, either for the minimum condition, or for a number of conditions, as desired. For such flight tests, it is suggested that the generator be replaced by a device which incorporates a pitot tube and means for opening or closing the end of the tube in flight. If a series of flight tests are taken using a single generator, only a single point will be obtained on each pressure-volume curve. It is obvious that at least two points, preferably well separated, are necessary to establish a curve. For this reason, the author suggests taking open-end and closed-end readings, since these two readings establish the complete pressure-volume curve, or at least a fair approximation of it. More points could be taken, if greater accuracy is desired. However, regardless of the number of points taken, if the curve of pressure versus velocity head can be represented by a straight line, this line can be represented by two constants h_c and R_t, representing developed pressure and tube resistance, respectively. When h_c and R_t are known, and when the air-flow resistance R_g of a generator is known, the total pressure across it, and the velocity head can be quickly and easily computed from equations 4 and 5. From the velocity head, the volume and weight can be determined as indicated in the following paragraphs.

Determination of Air Velocity, Volume, and Weight From h_v

For National Advisory Committee for Aeronautics sea-level conditions of 15 degrees centigrade and 29.92 inches mercury, it can be shown that

$$v_m = 3{,}967 \sqrt{h_v} \qquad (6)$$

(This equation is based upon an air density of 0.07651 pound per cubic foot, water density = 62.37 pounds per cubic foot, and acceleration of gravity = g = 32.18. It further assumes that the air is incompressible.) At any altitude, where the density of the air is ρ pounds per cubic foot

$$v_m = \frac{1{,}097}{\sqrt{\rho}} \sqrt{h_v} \qquad (7)$$

Or, in terms of temperature T (degrees centigrade) and atmospheric pressure b in inches of mercury

$$v_m = \left(1{,}279 \sqrt{\frac{273 + T}{b}}\right) \sqrt{h_v} \qquad (8)$$

Or, if an air-speed indicator is used, the speed may be read in miles per hour, the pressure altitude and temperature noted, and the true air speed computed with a navigational flight computer.

For all velocity-head measurements, the pitot tube should be in the center of the pipe and should be preceded by a straight section of pipe at least 10 diameters in length. Average velocity in the blast tube may be taken as 80 per cent of the maximum velocity; and, if the sectional area of the tube is A square feet, the volume flow, at sea level, is, from equation 6

$$V = 0.80 \times v_m \times A = 3{,}967 \times 0.80 \times A \sqrt{h_v} = 3{,}174A \sqrt{h_v} \qquad (9)$$

At altitude

$$V = 0.80 \times v_m \times A = \left(1{,}023A \sqrt{\frac{273 + T}{b}}\right) \sqrt{h_v} \qquad (10)$$

The weight flow of air, in pounds per minute, is at sea-level

$$W = 242.8A \sqrt{h_v} \text{ pounds per minute} \qquad (11)$$

at altitude

$$W = \left(753.4A \sqrt{\frac{b}{273 + T}}\right) \sqrt{h_v} \qquad (12)$$

Thus, from the measured velocity head h_v, can be computed velocity, volume, and weight. If the generator builder is given values of h_c and R_t for the blast tube, he only needs to determine the air-flow resistance of a new generator in order to compute the velocity head, and from it the volume and weight flow for this new design without waiting for a flight test. Obviously, the same process could be applied to several alternative designs to determine which one would be best in a plane from the standpoint of effective cooling.

The Concept of Air-Flow Resistance

Air-flow resistance has been defined in this paper in a manner analogous to resistance in an electric circuit, so that it can generally be used in a manner analogous to the use of ohms in calculating d-c circuits. For example, since the generator and blast tube are in series, their "air-flow resistances" can be added directly. But a word of caution is necessary. The air-flow resistances of all the elements in any given air circuit must all be computed on the basis of the same diameter of tube at which the velocity head is measured. For example, the air-flow resistance of generator A is 7.60 based on a two-inch blast tube; if the diameter of the entrance were changed to three inches without changing

the generator otherwise, the resistance would then be $7.60\times(3/2)^2=17.1$.

Air-flow resistance has been used in a number of unpublished reports, defined in various ways. To avoid confusion, it is suggested that a name be applied to the unit of air-flow resistance as defined in this paper. Since this unit is so defined that a resistance of n units means a lost head of n velocity heads, the name "velhead" is suggested as appropriate. For example, generator A has an air-flow resistance of 7.60 velheads based on a two-inch tube. If no tube diameter is specified, it will be generally understood that the resistance value is based on the actual diameter of the air entrance of the generator.

Generators With Internal Fan

An internal fan will have the general effect of increasing the air flow. Let the pressure of the internal fan be denoted by h_{gf}. This pressure will be proportional to the square of the revolutions per minute and to the first power of the air density; it can be represented by the equation

$$h_{gf}=F_p\times\left(\frac{N}{1{,}000}\right)^2\times\frac{\rho}{\rho_0} \qquad (13)$$

or

$$h_{gf}=F_p\times\left(\frac{N}{1{,}000}\right)^2\times\frac{0.9626b}{273+T} \qquad (14)$$

where F_p is an empirical constant. Physically, it is the pressure developed by the fan at sea level at 1,000 revolutions per minute. This constant F_p might be measured by blocking either the inlet or the outlet and measuring the pressure at the blocked end of the generator; readings should be taken at different speeds.

When supplied by a blast tube, the velocity head of air flowing may be computed from equation 4 by adding the fan pressure to the numerator or

$$h_v=\frac{h_c+h_{gf}}{R_t+R_g} \qquad (15)$$

The volume can then be computed by using equation 10 and the weight of cooling air by using equation 12. The total pressure h_g across the generator is

$$h_g=R_gh_v-h_{gf}=\frac{R_gh_c-R_th_{gf}}{R_g+R_t} \qquad (16)$$

Using these equations, it can be shown that if to generator B a fan were added capable of delivering 1.5 inches pressure at sea level, the volume of air through the generator would be increased seven per cent, but the pressure across the generator would be reduced from 6.16 inches to 5.60 inches, a decrease of nine per cent. (Without numerical values of the two constants of the blast tube, h_c and R_t, these calculations could not have been made.) It is obvious that the addition of the fan should increase the volume of air and decrease the pressure at the inlet of the generator; but to determine quantitatively how great this effect is, it is necessary to know the two fundamental constants of the blast tube, h_c and R_t.

Suggested Tests for Blast Tubes

For a given installation, and for a given set of conditions, that is, for a given indicated air speed and position of the shutters in any air ducts associated with the generator blast tube, two readings are required: an open-end reading, and a closed-end reading. A pitot tube is installed in a straight section of tubing $1^{15}/_{16}$ inches in diameter approximately 20 inches long; the impact tube should be in the center of the pipe. The total-head connection of the pitot tube is to be connected to the pressure side of the manometer, or air-speed indicator; the static-head connection should preferably be capped, and the exhaust side of the manometer should be connected to the chamber into which the generator would discharge its exhaust air. Provision must be made so that the end of the blast tube can be either sealed tight or opened wide during flight, at will. For each significant set of flight conditions, two readings of the blast tube are to be taken, as follows:

(*a*). *Closed-end reading*, h_c = total pressure head above generator air discharge chamber, in inches of water.

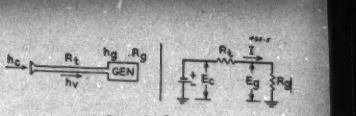
(*b*). *Open-end reading*, h_o = total pressure head above generator air discharge chamber, in inches of water. Record actual inside diameter of the pipe at the location of the pitot tube.

These tests are similar in principle to the classical open-circuit and short-circuit tests so frequently taken on various kinds of electrical machinery. The two blast-tube constants can be readily computed from these two readings as follows:

$$h_c=h_c \qquad (17)$$

$$R_t=\frac{h_c-h_o}{h_o} \qquad (18)$$

h_o is a velocity head since the static head when the tube is discharging freely, is zero. The altitude at which the plane is flying for these readings is not particularly important, since the density of the air should not affect the test results appreciably. If the velocity of air in the blast tube is desired for some reason or other, it may be determined from equation 8, the volume from equation 10, or the weight from equation 12.



No Fan in the Generator

Closed-end head = h_c
Blast-tube resistance = R_t
Velocity head of flow = h_v
Generator resistance = R_g

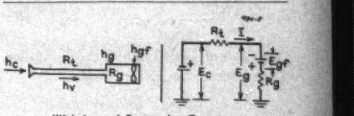
$h_v=\dfrac{h_c}{R_t+R_g}$

$h_g=h_vR_g=\dfrac{R_gh_c}{R_t+R_g}$

E_c = open-circuit volts
R_t = line resistance
I = current
R_g = load resistance

$I=\dfrac{E_c}{R_t+R_g}$

$E_g=IR_g=\dfrac{R_gE_c}{R_t+R_g}$



With Internal Fan in the Generator

$h_v=\dfrac{h_c+h_{gf}}{R_t+R_g}$

$h_g=h_vR_g-h_{gf}$

$=\dfrac{R_gh_c-R_th_{gf}}{R_t+R_g}$

$I=\dfrac{E_c+E_{gf}}{R_t+R_g}$

$E_g=IR_g-E_{gf}$

$=\dfrac{R_gE_c-R_tE_{gf}}{R_g+R_t}$

Note: If h_g is $-$, generator fan helps overcome R_t as well as R_g, and more air would flow through generator if blast tube were removed from generator.

Note: If E_g is $-$, E_{gf} helps overcome R_t as well as R_g, and more current would flow if terminals E_g were short-circuited.

Figure 5. Electric circuit analogue

Tests to Determine Air-Flow Resistance of Generators

Generator air-flow resistance can be measured in the laboratory by applying a total head, h_g, to the generator air inlet, and measuring the velocity head, h_{vg}, in the blast tube. The air flow resistance of the generator is:

$$R_g=h_g/h_{vg} \qquad (19)$$

Values of R_g were determined experimentally by G. G. Setterlund, who obtained the results shown in Table I.

These results indicate that there is some variation in air-flow resistance with temperature and with speed and, although these changes are comparatively small, it is recommended that the air-flow resistance be measured at conditions ap-

Table II. Air Pressures on Generators During Flight

(Reference, Figure 4)

	Generator A	Generator B	Generator C
According to curve 1.....	10	10	6.9
According to curve 2.....	6	6	6
According to curve 3.....	6.55	6.17	4.28
According to curve 4.....	6.33	6.10	4.79

proximating full-load temperature and normal operating speed.

If the generator has an internal fan, the pressure h_{sf} from it at normal operating speed should first be measured by blocking the inlet or exit. Then, with the machine operating at the same speed and at approximately full-load temperature, impress a head h_s and measure the velocity head h_{sv} of the inlet air. The air-flow resistance will be:

$$R_g = \frac{h_s + h_{sf}}{h_{sv}} \qquad (20)$$

This value of R_g will include the resistance of the internal fan, as it should.

Factors Affecting h_e

If the air scoop were out on a wing where it was unaffected by the slip stream, as pitot tubes for air-speed indicators are, and if the air from the blast tube were discharged to atmospheric pressure, h_e would be simply the airplane pitot pressure, which is the same for all planes. It would be approximately

$$h_e = \left(\frac{\text{indicated miles per hour}}{45.1}\right)^2 \qquad (21)$$

(For high air speeds, h_e would be slightly more than indicated by the above.) If the scoop is behind the propeller, h_e could be considerably above airplane pitot pressure. However, if the back pressure in the air discharge chamber is substantially above airplane static pressure, as tests indicate it often is, the net pressure h_e may be either greater or less than airplane pitot pressure, that is, greater or less than would be indicated by equation 21. An ideal arrangement would be a short tube with a minimum number of bends, with a curved-funnel scoop directly in the propeller blast, as shown in Figure 3A.

Quite different is the arrangement shown in Figure 3B where the generator air supply line is merely tapped into a larger blast tube supplying the oil cooler, intercooler, or both. In this case, h_e will depend not only upon the speed of the plane, but also upon the position of the shutters; h_e will be greater when they are closed than when they are open. The quantity h_e can be increased some by use of a scoop at the entrance to the generator tube to take advantage of the velocity head of the air in the main duct. For this arrangement, the worst condition is with shutters wide open and plane flying at minimum speed.

If a flexible air tube is used, there may be considerable air leakage, which will reduce appreciably the observed values of h_e and h_s.

Factors Affecting R_t

The air-flow resistance of the blast tube, R_t takes into account the head losses in the blast tube including entrance losses. Numerically, it is equal to the number of velocity heads lost in the tube. The losses consist principally of: entrance losses, fluid friction at the sides of the tubes, losses in elbows or bends in the tube, and losses from changes in cross-sectional area of the tube, if any. The loss at the entrance is affected by the shape of the entrance. Figures 3C to 3F show different shapes of entrances and the probable head loss due to each. (These are the head losses usually obtained when a constant static head is maintained at the entrance; whether or not the same losses are obtained when the tube itself is moved against the air is problematical, but it seems reasonable to suppose that these figures do afford a comparison of the relative effects of different shapes of entrance.)

In general, in any fixed plane installation, the tube resistance R_t probably does not change greatly with changes in plane speed or changes in shutter position. However, there may be an exception in the case of an installation such as Figure 3B if the amount of air drawn by the generator is an appreciable part of the total air, because the air drawn by the generator will increase the drop between the entrance of the main scoop and the entrance to the generator tube. Thus, with shutters closed, both h_e and R_t may be higher than when the shutters are open.

Blast-Tube Specifications

Pressure-volume curves corresponding to four different blast-tube specifications are given in Figure 4, together with pressure-volume curves of three representative aircraft generators. Curve 1 illustrates specification 95-32275, amendment 2, dated March 3, 1942, which specifies ten inches total pressure, but not over 100 cubic feet per minute; the vertical line is drawn at a velocity head corresponding to 100 cubic feet per minute. Curve 2 illustrates specification ANG-1-13 which specifies six inches of water, with no limit on volume. No blast tube could have a pressure-volume curve corresponding to either curve. Curve 3 is the pressure-volume curve repeated from Figures 1 and 2 of this paper. Curve 4 shows a different idea as to what the true pressure-volume curve may be. According to these specifications, the pressures received by the three generators in flight will be indicated by the points of intersection (Table II). Then, according to these specifications, the pressures impressed on the generator for chamber tests should be according to the table.

Taking curve 3 as a reasonable representation, it is suggested that the specification for a two-inch diameter blast tube might be worded somewhat as follows:

> The blast tube shall be designed to deliver, for any condition of flight, a total pressure head at the end of the blast tube of at least ten inches of water when the end is closed and at least two inches of water when the end is not restricted. This pressure head shall be the total head at the end of the tube above the ambient air pressure in the generator compartment. When the open-end reading is being taken, the blast tube shall be discharging its air into the generator compartment and the pitot tube shall be in the center of a two-inch-diameter straight pipe preceded by a straight length of ten or more diameters.

Such a specification would be more informative and helpful to a generator designer, than present specifications, because he could then determine in advance what air pressures and volumes his generator would receive in flight. Moreover such a specification would be of advantage to a procuring agency when any new generator was received because it could run a simple air-flow test on the generator in the laboratory, and by very simple calculations determine the pressure and volume the generator would receive in flight, *without actually making a flight test.* This same pressure could be applied in laboratory chamber tests. However, it is to be hoped that pressure-volume curves for representative installations will be obtained by actual flight tests so that specifications can be based on actual conditions.

It should be emphasized here, that there is no magic figure for the air requirement for any generator; in general the more air it gets, the better will be the performance, which may show up in the form of more load capacity, particularly at a high altitude, lower temperature rise, greater reliability, or longer life.

Conclusions and Remarks

Fundamental theories of blast-tube cooling have been developed and their use explained. The problem of blast cooling is broken down into two parts: a study of the blast-tube installation itself, and an independent study of the generator itself. It is shown that the performance of the blast tube can be expressed in terms of two factors: internal pressure h_s (that is, pressure available with no flow) and air-flow resistance R_t, a quantity analogous to ohms in a d-c circuit. Values of these two constants, which vary somewhat, de-

pending upon the installation, upon plane speed and other factors, are all that is required to predict the air flow through a generator which has been tested independently of the blast tube. Tests on the generator alone can be made to yield, in the case of a generator with no internal fan, a single constant, the air-flow resistance R_g. If the generator has an internal fan, more tests are required on the generator to determine the characteristics of this fan, but no more tests are required on the blast-tube installation. In general, the method of attack is: first, the air-flow resistances of the generator and blast tube are obtained; second, the velocity head of air flow is computed from the closed-end pressure and resistances; third, the velocity, volume, and weight are then computed from the velocity head.

A more rational and illuminating method of specifying the minimum characteristics of a blast tube is proposed. The new method of specification would provide the airframe builder with a clear-cut specification which could be used for design and checking of the blast tube, it would provide the generator builder with a rational basis for designing his cooling system in the generator for maximum effectiveness, and, further, would provide a simple method for determining what pressure to apply to any given generator for sea-level tests, either at atmospheric pressure or in an altitude chamber.

The equations developed for blast-tube cooling are compared with similar equations for electric circuits in Figure 5.

Symbols

A = cross-sectional area of blast tube at pitot-tube location, square feet.

b = atmospheric pressure of air, absolute, in inches of mercury.

F_g = pressure coefficient of the internal fan of a generator. See equation 13.

H_f = lost head (Figure 3).

h_g = total head across the generator, inches of water.

h_{gf} = pressure developed by an internal fan, inches of water. See equation 13.

h_c = total pressure head at generator end of blast tube above generator ambient, end of tube closed.

h_o = total pressure head at generator end of blast tube above generator ambient, end of tube wide open and unobstructed.

h_v = velocity head, in inches of water.

h_{vg} = velocity head in blast tube when supplying air to a generator.

N = revolutions per minute of the generator.

T = temperature of air entering blast tube, in degrees centigrade.

R_g = air-flow resistance of a generator. Defined in equations 1, 19, and 20.

Aids to Quality Control in the Manufacture of Aircraft Generators

F. M. POTTER
NONMEMBER AIEE

AIRCRAFT generators are designed for high output, low weight, small size, and wide speed range. These limitations require close designs which do not permit normal allowances for material and manufacturing variations. Small variations in the material and manufacturing processes result in wider variations in output characteristics than in conventional machines.

It is the purpose of this paper to discuss certain of these variations; their effect on the output characteristics of the machine, and to illustrate means of checking and controlling these factors.

Factors Affecting Output Characteristics

1. Shunt-field ampere turns available, compared to those required by the magnetic circuit, determine the base or underspeed characteristic.

2. Type of insulation, heat transfer coefficients, shape and size of cooling ducts, and the amount of cooling air taken through the generator determine the losses which can be dissipated; and in turn, the output rating.

3. Commutating ability, generator stability, temperature rise, and mechanical construction determine the top operating speeds.

Variations Affecting Required Shunt-Field Ampere Turns

For a required total flux, shunt field ampere turns are affected by the following:

1. Variations in air-gap length.

2. Variations in iron portion of the magnetic circuit.

(a). Magnet frame—permeability.

(b). Main poles—stacking factor and permeability.

(c). Armature punchings—stacking factor and permeability.

3. Variations in compensation of armature reaction.

Variations Affecting Temperature Rise

The temperature rise of an aircraft generator depends mainly upon:

1. The total losses.

2. The amount of cooling air.

3. The effectiveness of this cooling air; that is, where it goes and the area of winding surface it wipes.

Variations in Final Machines—Testing Technique

The assembled generator combines all the variations of its individual parts and then is subject to the variations of testing technique, which, when broken down, consist of: brush fit, brush setting, instrumentation, and the human element.

Variations in Air Gap Length

In the General Electric type P-1 aircraft generator rated 30 volts, 200 amperes, 2,200/4,500 rpm, forced-cooled, six-inches-water air pressure, approximately 70 per cent of the shunt field ampere turns are consumed in the nominal air gap. This part of the magnetic circuit, therefore, warrants all possible control of its variations.

Drawing tolerances, consistent with manufacturing capabilities and engineering requirements, permit a normal variation in the air gap.. In addition to

Paper 44-83, recommended by the AIEE committee on air transportation for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944. Manuscript submitted February 17, 1944; made available for printing March 13, 1944.

F. M. POTTER is in the aircraft generator division, motor engineering department, General Electric Company, Lynn, Mass.

R_t = air-flow resistance of a blast tube. Defined in equation 2.

r_m = maximum velocity of air (at center of blast tube) in feet per minute.

V = volume of air flowing, in cubic feet per minute.

W = weight of air flowing, in pounds per minute.

ρ = density of air, in pounds per cubic foot.

ρ_0 = density of air at NACA sea-level condition (15 degrees centigrade, 29.92 inches of mercury) = 0.07651 pound per cubic foot.

Figure 1. Equipment for determination of gaps between magnet frame and main poles

the expected variations are the unexpected and undesired variations due to faulty manufacture and assembly of parts. It is these undesired variations which are eliminated by means of a special device termed a "gap checker." See Figure 1. In reality this device searches for and locates gaps between the main poles and the magnet frame.

The "gap checker" works on the bridge-circuit principle, using either flashing direct current or low-frequency alternating current as a source of power for the excitation coil. Intimate contact with the poles being checked is obtained by making the radius of the leg faces equal to that of the pole bore, and then supporting the entire weight of the field assembly from the contact faces.

If the total flux divides equally between the two parallel paths, the voltage induced in each of the bridge coils will be the same, and since they are connected opposing, no voltage will be read on the instrument. This indicates that both poles being checked are identical with regard to contact with the frame.

The air gap on the side opposite the poles being checked is large so that variations on this side of the field assembly will have little or no effect on the flux division in the legs of the device.

Experience in using this "gap checker" shows that there is usually a small voltage showing on the instrument if the poles have a normal fit against the frame. The center-zero instrument is therefore blocked off in red except for a small portion around the zero. If the needle goes into the red portion, one of the poles being checked has a gap in back of it. To determine which of the poles has the gap, the frame is rotated one pole pitch and the test repeated. If the high reading still exists, the pole of the original pair still being tested is the one at fault. If the high reading no longer exists when the frame is rotated one pole pitch, then the faulty pole is that one of the original pair which is not in the second pair.

Strictly, this device is a comparator, comparing the magnetic circuit of adjacent main poles. The use of such a device is based on manufacturing experience which shows that in those field assemblies faulted for this cause, there is usually only one faulty pole and seldom if ever more than two.

Figure 2. Test equipment for determination of magnet-frame permeability

Figure 3. Equipment for spot-checking main-pole stacking factor and permeability

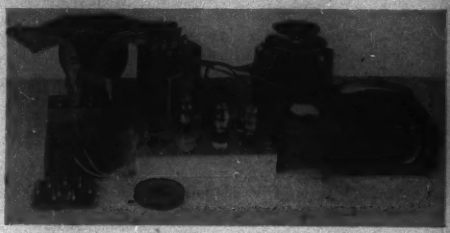


Figure 4. Armature-punching - permeability meter

Variations in the Iron Portion of the Magnetic Circuit

Magnet Frame

During these wartime conditions, it has sometimes been found necessary to accept inferior and variable magnet-frame materials in order to keep the production lines going. Laboratory tests of several samples have shown the frame material to be extremely variable in its magnetic properties, some of it good, some of it definitely bad, and some of marginal properties. A laboratory test of each frame is obviously a production impossibility.

The "frame tester" shown in Figure 2 was therefore designed for making quick production line checks of the magnetic properties of the frame material.

The "frame tester" consists of a standard *P*-1 generator armature supported in a structure which includes one fixed main pole and one movable main pole 180 degrees apart. Field coils separately excited supply the required ampere turns. The armature is directly connected to and driven at constant speed by a one-quarter-horsepower induction motor. The voltage generated in the armature is picked up by a pair of brushes and read with a standard d-c voltmeter.

To check a frame, it is necessary to take only one reading. The frame to be tested is slid into position. Then, with the armature running, the field circuit is closed and a specified field current set. The armature voltage is then read. This reading is indicative of the magnet-frame permeability.

The value of this "frame tester" is that poor material is rejected at the earliest possible stage in the manufacturing cycle; that is, immediately after the boring and turning operation.

Figure 5. Equipment for preliminary test of armatures

Figure 6. Current-balance test equipment

Main Poles

Rigid adherence to specifications by the vendors of magnetic sheet steel, careful laboratory checks of all shipments received, and accurate control of annealing processes have resulted in little or no trouble magnetically in main poles.

However, as a guard against any trouble which might arise due to substandard poles, and thus interfere with production, the equipment shown in Figure 3 was made for making spot checks on various lots of poles.

The "pole tester" is similar in principle to the "frame tester" in that a voltage generated in a standard armature at a definite value of field excitation is the criterion for a passable pole. In this device the pole to be tested is slid through the opening in the mounting flange and screwed into position opposite a fixed pole around which the exciting coil is mounted. Poles to be so tested are ground to a definite radial length so that air-gap variations will not enter into the result.

Figure 7. Shunt-field-coil mold and short-circuit tester

Figure 8. Shunt-field-coil turn counter

Armatures and Armature Punchings

In addition to standard laboratory tests on magnetic sheet steel for armature punchings, it has been found desirable to make spot checks of armature punchings after the annealing process. The annealing process is of course an important operation and if done improperly, the punchings will not equal the required magnetic values.

An "armature-punching tester" is shown in Figure 4. A single armature punching makes up the magnetic circuit. Low-voltage 60-cycle alternating current obtained by means of a Variac transformer and a current transformer is applied to the one-turn winding through and around the core section of the armature punching. For a specified exciting current, the voltage induced in a five-turn secondary, which is proportional to the flux carrying properties of the punching, is read. Comparison of this reading to a minimum standard for the particular thickness of the punching indicates whether the punching is up to specified requirements.

Figure 5 shows equipment known as an "armature tester." This equipment consists of a pair of short poles mounted on a bed plate together with a pair of brush holders and brushes, a fixed ball-bearing holder on the drive end, and an adjustable ball-bearing holder on the opposite end which permits the device to be used for testing six-pole armatures of various heights of iron.

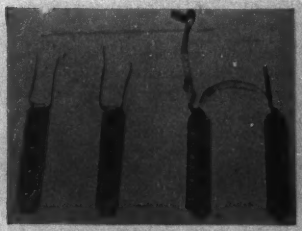
To test an armature, lapped ball bearings are placed on the armature shaft, the armature put into position, and the drive shaft brought into engagement with the inner splines of the armature shaft. The motor is then started up, a definite exciting current applied to the field coils, and the voltage generated by the armature read. If the voltage reading is below a specified value, the armature is rejected.

By means of this device, the following faults are determined:

1. Poor magnetic properties of the stacked core.
2. Wrong connections of the armature winding.
3. Short circuits in the armature winding.

(A)

Figures 9A and 9B. Shunt and commutating coils, before and after molding



(B)

Variations in Compensation of Armature Reaction and Interpole Strength

The armature reaction per pole at full rated current of the General Electric type *P*-1 aircraft generator is 960 ampere turns as compared to a maximum of 480 ampere turns in the shunt field. Pole face or compensating windings are therefore used to neutralize partially the effect of the armature reaction. Interpoles and interpole windings are also used to obtain sparkless or "black" commutation throughout the speed and load range. These windings are connected in three parallel circuits, each circuit consisting of two commutating and two compensating coils in series.

To obtain the full benefit of these compensating- and commutating-pole windings, it is necessary that the three parallel circuits balance and that the load current divide equally between them.

Due to difficulty in accurately measuring these low-resistance circuits, a check of actual current balance is taken by means of the special setup shown in Figure 6. A small arc welder supplies approximately 75 amperes and the division of this current between the three field circuits is simultaneously read on the three ammeters. Limits of unbalance have been set beyond which fields are rejected. This test has proved its worth to the extent that two such stations are used, one before the field is impregnated, and the other just before the field is assembled into the final machine.

At the first station, that is, before the impregnation treatment, immediately after the current readings balance are taken and with current still flowing, a polarity check of the windings is made by use of a compass.

Variations Affecting Temperature Rise

In a forced-cooled aircraft generator practically all of the losses are carried away by the cooling air. It is, therefore, of paramount importance to obtain the maximum possible amount of cooling air through the right passages and to have this air wipe the maximum area of winding surface.

The General Electric type *P*-1 generator has been designed with several ducts through the field and with the maximum area of winding surface exposed to the cooling air. These ducts result naturally when the shunt and commutating coils occupy their allotted space. In order to maintain uniform air ducts through the fields, it is necessary to shape the shunt coils and to compress and mold

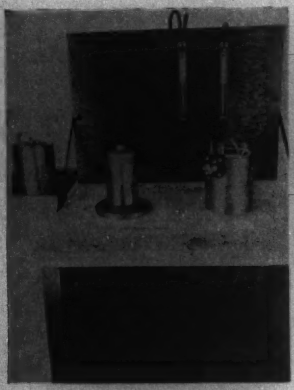


Figure 10. Field air-flow measuring instrument

them to a definite size. To do this, these coils after being wound on standard winding machines are impregnated in a molding varnish, pressed and baked in heated molds as shown in Figure 7.

Coils, when removed from the press and while still hot, are checked for short circuits on the "short-circuit tester" shown also in Figure 7. This device is a sensitive bridge circuit operating on 60 cycle power. A short circuit in the coil unbalances the magnetic field causing the instrument needle to deflect.

Figure 8 indicates still another checking station, this time a "turn counter." Shunt field coils which have passed the "short-circuit tester" are checked for proper number of turns by balancing the voltage generated in the coil undergoing test to that of a standard coil. The instrument is marked off to permit coils to pass with plus or minus one turn from the standard.

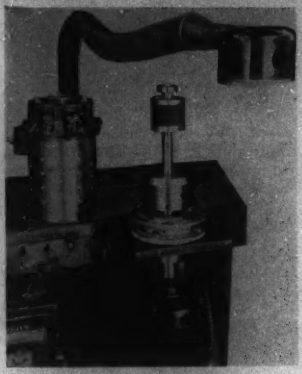


Figure 11. Brush-seating machine

Figure 12. Motor run-in stands

Commutating coils are wound in what is termed a "back turn winding" directly onto the insulated pole. These wound poles are then placed between hot pressing plates, pressed to definite dimensions, and baked to set up the special thermo-setting varnish on the glass covered wire.

Figures 9*A* and 9*B* show shunt and commutating coils before and after molding. Note also the portion of the commutating pole projecting beyond the winding. This is the frame side of the pole, and when the pole is assembled into the magnet frame, an air duct is obtained between the frame and the under side of the commutating pole winding. Such molded shunt and commutating coils also provide an air duct between the shunt and commutating coils.

Manufacturing variations may result in too little air flow through the field. A "field-air-flow measuring instrument" as shown in Figure 10 was therefore designed in order to check the air passages through the field. The instrument is located in the production line at an early stage in the manufacturing cycle, where a field can be easily repaired if it has been rejected for restricted air passages.

The "air-flow instrument" consists of a blower which forces the air through an air-flow-measuring box shown under the table. A short pipe connects the exhaust of the box to the flange on which the field assembly is placed. A dummy armature forces the air to go through the passages in the field.

To make use of this instrument, a field assembly to be checked is placed over the dummy armature and rested upon the flange. A static pressure of 2.5 inches of water, measured in the pipe just below the flange, is set, and the differential

Figure 13. Generator test stands

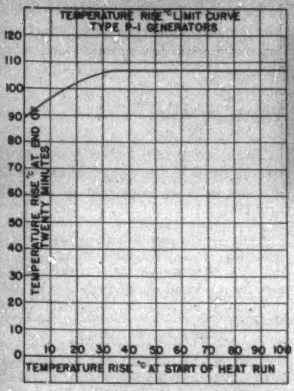


Figure 14. Shunt-field temperature-rise curve

pressure across the orifice in the air-flow box is read. This reading determines the air flow through the field.

Tests have shown that by means of this device, the temperature rise of any field can be quite accurately predicted.

Variations in the Assembled Generator

The assembled generator combines all the variations and tolerances of its individual parts. It is only by diligently and resourcefully controlling the variations of these component parts that consistent generators are manufactured.

The assembly and final test of the completed generators bring out the inconsistencies and reject those generators which do not meet specification requirements. Here again, however, variations arise in the tests themselves. Testing variations can be controlled by:

1. Proper supervision and instruction of the testers.
2. Proper instrumentation.
3. Proper brush fit and correct brush setting.

Figure 11 shows a "brush-seating machine" which is a very definite aid in obtaining excellent brush fits in a short time. Brushes as received from the vendor are ground to approximately the correct radius. The brush rigging with the brushes in place is assembled with the field and endshield, all screws are tightened, and the brush rigging set in approximately the correct position. The "brush-seating machine" is then used to obtain a nearly perfect brush fit. The combined assembly; field, brush rigging,

Figure 15. Vibration test stand

and endshield is placed over the arbor. The brushes are placed in their respective holders onto the grinding arbor, and held in their normal position by the brush springs. The exhaust hood is dropped over the endshield, the motor started, and allowed to drive the grinding arbor in the normal direction of rotation for approximately 15 seconds. At the end of this time, the brushes are properly fitted and very nearly polished.

The abrasive for this fixture is crocus cloth. The diameter over the crocus cloth is equal to the nominal diameter of the commutators. Very little of the brush is removed during this operation, the maximum amount ever experienced being not over 0.010 inch.

Figure 12 shows a pair of motor run-in stands where the generators are run as motors for approximately five minutes to perfect the brush fit. Occasionally a machine requires the application of a soft "brush-seater" to obtain the required brush fit. Here, also, electrical or so-called "inductive neutral" is located, and the brush rigging set in this position. The generator is then sent on to the final test.

Final Test

Figure 13 shows a group of test stands where the generator receives its final tests. These final tests consist of the following:

1. Setting of final brush position.
2. Base-speed heat run.
3. Regulation at base and top speeds.
4. Commutation check at top speed, full load.
5. Overspeed test.
6. Repeat of number 4.
7. Vibration reading—generator run as a motor.
8. High potential test.

Because of certain unique features, two of the tests listed will be discussed briefly.

Base-Speed Heat Run

All generators are subjected to a base-speed full-load heat run, the duration of which is either 20 minutes or until temperatures and field current readings have stabilized. Test limits for 20 minute runs have been established whereby a generator having a temperature rise of X degrees centigrade at the start of the heat run must not exceed Y degrees centigrade temperature rise at the end of 20 minutes, or more than a certain value of field current; otherwise, the heat run must be continued to the stabilization point. These limits of temperature rise for 20 minute heat runs are shown in the form of a curve in Figure 14. This curve is the result of a large number of tests and assures that any generator meeting the 20 minute heat run limits will meet the limits for ultimate heat runs.

To obtain consistent and accurate heat run data, each test stand is equipped with identical blast tubes and covers as shown in Figure 13. All voltmeters, ammeters, air-pressure gauges, and speed tachometers are carefully checked, and recalibrated, if necessary, at least once a week.

Vibration

Vibration or balance readings are taken on each generator after the completion of tests. With the generator mounted in the "vibration stand" as shown in Figure 15 and running as a motor, actual vibration readings are taken at each end of the generator by means of an electric vibrometer.

The vibration stand itself consists of a somewhat flexible steel table on which is mounted a heavy steel plate insulated from the table top by means of sponge rubber pads. The generator to be tested is mounted on a felt pad in a "V" shaped wooden block which in turn is insulated from the steel plate by means of sponge rubber pads. The electric vibrometer is mounted directly on a heavy steel block. The design and construction of this equipment eliminates external vibrations and well insulates the generator from the vibrometer.

Conclusion

Certain devices and means have been shown which are definite aids to quality control in the manufacture of aircraft generators. New problems will require new aids. This is but one of the many tasks of the engineer today.

Behavior Factors of Rectifier-Driven D-C Motors

VICTOR SIEGFRIED
MEMBER AIEE

Synopsis: In the rapid development and application of rectifiers to drive d-c motors, certain factors which influence the behavior of the motor may require unaccustomed consideration. The pulsating nature of currents which may be encountered introduces departures from conventional treatment of (1) heating value of the current waves, (2) stresses upon the insulation and commutator resulting from high peaks of voltage involved, and (3) torque pulsations tending to produce vibration and noise.

Analysis is made from experimental and theoretical approaches of possible ratios of the heating values to be expected with typical wave shapes applied to electronically driven motors. The ratio of effective to average values of current varies with the load on the machine and with the number of tubes used in the rectification process. It is shown that the problem is most acute in machines of small rating where mechanical inertia is low and where tube capacities would permit the use of but one or two tubes for economy of materials. This situation may require "overmotoring" an application in order to allow the required thermal capacity. Vibrations which will otherwise show up in undesirable effects on the driven machine, and noise, would also dictate the use of larger machines than necessary with conventional d-c practice.

The conclusion is drawn that factors not at first apparent must be considered in the application of the rectifier drive, and that as many phases as practicable are desirable in the rectifier.

THE electronic rectifier is currently achieving considerable prominence as a source for d-c motors.[1-5] It has many advantages over both fixed- and variable-voltage generator systems in the reduction of critical materials and elimination of rotating parts in the conversion process. Furthermore, its ease of control by means of the grid-phase-shifting system of the thyratron or the ignitron suggests many applications where new results can be secured.

In the use of phase-controlled rectifier sources for d-c motors, considerable attention must be given to the wave shapes of the currents supplied to the machine and their effects on it. Whereas continuous and direct currents have long been considered synonymous, there is introduced a new concept of *direct* current which may be pulsating but still continuous or even may be discontinuous for large fractions of a cycle. These differences from the continuous and substantially steady values encountered in conventional d-c practice produce far-reaching and sometimes surprising effects. They show that the rectifier is not inherently a panacea for all ills, but rather introduces problems of its own which can be met and conquered if recognized.

Paper 44-86, recommended by the AIEE committee on electrical machinery for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944. Manuscript submitted February 21, 1944; made available for printing March 14, 1944.

VICTOR SIEGFRIED is assistant professor of electrical engineering, Worcester Polytechnic Institute, Worcester, Mass.

Nature of Problems

The controlled rectifier is inherently a phase-angle-control device which delays the beginning of current flow to a predetermined point in the cycle of alternating voltage applied to the tubes. For single-tube half-wave rectifiers, the result is pulses of current which can never be continuous but will always be less than one-half cycle in length. With two tubes in a full-wave rectifier, the current produced will be pulsating but seldom can be continuous. In polyphase systems with three or four tubes the voltages will overlap and the currents can become continuous when the rectifier is turned full on. With six or more phases, the possibility is reduced that phase control will produce discontinuous currents for any but the lowest of output levels. With sufficient number of tubes, the current pulses of the individual tubes are smoothed out, and the resultant current approaches the steady value of generator-produced current.

Thus the region in which these problems are encountered is confined to rectifiers using only a few tubes and in which the output is either discontinuous or else contains an appreciable ripple component.

There are a number of methods, inherently expensive, for filtering this output to make it smooth by the time it reaches the motor. Combinations of inductance and capacitance are required. Inductance in the machine may help as in the field circuit, where the machine is somewhat self-filtering. In the armature circuit, however, a high inductance interferes with commutation and is to be avoided.

Effects on Motor

There are certain factors which must be considered in analyzing the behavior of d-c motors when subjected to currents of this type.

1. The current produced by the rectifier is pulsating. It may be continuous but pulsating to a high degree, or it may even be zero for a portion of the cycle and be discontinuous, which is the more aggravated situation.

2. In order to achieve a required average value of current, this pulsating current must have peaks which are much larger in value. This results in an effective or root-mean-square current much larger than indicated by d-c ammeters.

3. The heating value of these pulsating waves is much greater than for the equivalent amount of conventional direct current. The resistance takes on an effective value which is larger due to stray-load-loss components, and the high peaks of current involved thus make the total I^2R loss far greater than ordinarily anticipated.

4. Peaks of voltage in the armature will be encountered due to the interaction of the pulsating current and the inductance of the armature and anode transformer circuits. These give a voltage wave shape in which the d-c value is almost unrecognizable, with peaks three or four times as large as the voltmeter value. These voltages endanger the armature and commutator insulations, and in some cases, commutator sparking is a direct consequence of the instantaneous peaks.

5. Torque produced by the machine becomes pulsating, with its attendant noise and vibration problems. These may be reflected in unsatisfactory performance of the driven machine, especially at light load or low speeds.

Analysis of Current Output

With current wave shapes as variable as occur in these rectifier drives, no one method of attack fits all cases. Where current is continuous but pulsating, it may be analyzed much as an average value with superimposed ripples of high frequency. The fundamental of this harmonic will be the supply frequency times the number of phases involved.

For discontinuous waves, the effect on the machine is more serious. Fortunately the analysis is quite simple due to the fact that the armature current pulse approximates a half sine wave, regardless of the portion of the cycle which it occupies. This is due to the influence of the inductance of the circuit, tending to hold the current rise down, and main-

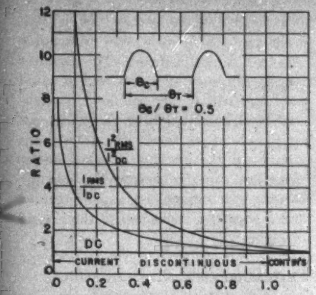


Figure 1. Effect of angle of conduction on heating and current ratios

Insert: Example of wave shape when $\theta_C = 0.5\theta_T$

tain current flow past the voltage zero. Vedder and Puchlowski[4] have given good detailed analyses of this, but for purposes of this paper, the approximation to the half sine wave is adequate. In the following analysis, it is to be re-emphasized that the range in which more serious differences occur is at light loads and low speeds, depending on specific applications of the drive.

The main comparison of heating values, the most important difference, is in that of the average and effective values. The peak value of current, I_m, is used as the comparison figure in each case. For any given sine-wave pulse of half-cycle value as in Figure 1, the average value over that time is $2I_m/\pi = 0.636\,I_m$ and the effective value is $0.707\,I_m$. In averaging the current over a complete cycle, it will be in proportion to the ratio of angle of conduction, θ_C, to the total cycle, θ_T, but the effective value will be the square root

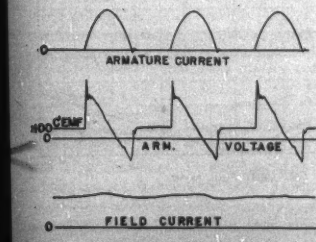


Figure 2. Oscillograms of machine currents and voltage for $\theta_C = 0.53\,\theta_T$

Armature current = 1.55 amperes root-mean-square and 1.09 amperes direct current
Armature voltage = 147 volts root-mean-square and 100 volts direct current
Field current = 0.360 amperes root-mean-square and 0.340 amperes direct current

Table I. Effective and Average Current Ratios for Discontinuous Currents

Conducting Portion of Period, θ_C/θ_T	D-C (Average) Values		Root-Mean-Square (Effective) Values		Current Ratio, I_{RMS}/I_{DC}	Heating Ratio, I_{RMS}^2/I_{DC}^2
	$\times I_{max}$	$\times I_{max}^2$	$\times I_{max}$	$\times I_{max}^2$		
0.10	0.064	0.004	0.223	0.050	3.49	12.5
0.25	0.159	0.025	0.354	0.125	2.24	5.0
0.33	0.212	0.045	0.407	0.166	1.92	3.70
0.50	0.318	0.101	0.500	0.250	1.57	2.49
0.67	0.424	0.180	0.577	0.333	1.33	1.85
0.75	0.477	0.228	0.612	0.375	1.28	1.65
0.90	0.572	0.327	0.671	0.450	1.17	1.38
1.00	0.636	0.405	0.707	0.500	1.11	1.23
Multiphase	1.0	1.0	1.0	1.0	1.0	1.0

Note: Table based on $I_{max} = 1.0$, and $R_{eff} = R_{d-c}$. Specific application of these data to rectifier-driven motors requires determination of actual current wave shape for each load and operating speed adjustment.

of the average square. For the case shown in Figure 1 where the current flows for one half the time, the effective value will be $0.5\,I_m$, whereas the average (d-c) value will be $0.318\,I_m$, a ratio of 1.57 to 1. Thus the true heating I^2R value of the wave will be $0.25\,I_m^2$ whereas that indicated by a d-c instrument will be $(0.318I_m)^2$ or $0.101\,I_m^2$, a ratio of $2^1/_2$ to 1. In the case of current for one-third of a cycle, the ratio is even more striking, as the heating rate is 3.7 times that of the equivalent smooth direct current. Relationships for other conduction periods are shown in Table I and Figure 1. These also show that for the limiting case of multiphase operation, these ratios become 1.0, and average and effective values are equal.

A typical oscillogram of voltage and currents in an actual full-wave rectifier-driven machine is shown in Figure 2. Conduction is for 53 per cent of the half cycle. The values of effective and average values are shown, and agreement is quite close to the anticipated values from Figure 1 for this setting of the control. This indicates that the sinusoidal approximation is in quite close agreement to actual conditions.

Such an example will apply equally well to any number of phases in a rectifier if the conduction period is one half of the portion of the cycle assigned to each phase. Thus, the case shown would be like a half-wave circuit conducting 180 degrees per anode, or a full-wave circuit conducting 90 degrees per anode, or a three-phase circuit conducting 60 degrees per anode, and so forth.

Results of Analysis

When, as in the examples shown, current is operating in the discontinuous range, the motor heating rate due to copper loss alone will be excessively large for the intended rating. The remedy would appear to be to figure the duty cycle carefully to include these effects, or simply allow a step-up in the motor size to provide a safety factor. The obvious alternative is to allow the motor to run hotter and hope that the life of the insulation will be satisfactory.

Another factor which contributes to the machine's running hotter is the core loss. While the current may be self-smoothing to a large degree, there is a high-frequency flux pulsation which will occur where there is usually no impediment to eddy-current losses. This would indicate the desirability of laminated core and pole pieces.

Two other factors which combine against the life of the insulation are vibration and voltage stresses. The probable life of the insulation seems doomed to be shorter than for conventional motors regardless of heating. The combination of excessive voltage strains, chafing under vibration conditions and higher temperatures indicates that much more or better insulation must be built into the machine's design.

The remedy really lies in careful engineering of an application. The load can be figured to keep the motor working in the continuous current portion of the rectifier operation. Multiphase rectifiers can be used, so as to approximate the steady current of a generator as nearly as economically feasible.

Conclusions

This analysis of the application of phase-shift-controlled rectifiers to d-c motors leads to these conclusions:

1. Consideration must be given factors not usually encountered in d-c machine practice.
2. These factors are most acute in machines of small rating where the mechanical inertia is low and the load requirements justify the use of only one or two tubes.
3. Heating of the motor will be increased by the use of rectified currents over conventional direct current, especially if machine currents are discontinuous.
4. Vibration will be especially prominent at low speeds.
5. Excess heating and vibration become of

A Unit for Balancing the Voltages of Three-Phase Aircraft Inverters Supplying Large Single-Phase Loads

SYDNEY WIMPIE
ASSOCIATE AIEE

Synopsis: A means of reflecting a single-phase load so it appears as a balanced three-phase load to the power supply is discussed in this paper. A balancer of this type, designed for use in aircraft, is described and its characteristics discussed.

Background

THE increase in electrically powered and electrically controlled equipment on aircraft has made it necessary, in certain cases, to add sizable single-phase loads to three-phase inverters. The nature of the existing three-phase load, however, placed severe restrictions on the permissible voltage unbalance. The need was felt for a means of maintaining balanced voltages between phases of a three-phase inverter operating under the conditions described above. As this balancer was to be used on aircraft, the further limitations that it be light in weight and efficient in operation were imposed.

In February 1943 a request was made by the Army Air Forces at Wright Field for a balancer of this nature. The single-phase load specified was approximately 265 volt-amperes, 115 volts, 94 per cent power factor, 400 cycles. The power supply was a three-phase inverter rated at 750 volt-amperes, 115 volts, 400 cycles.

The Balancer

Several methods of attaining the desired results suggested themselves. The one decided upon[1] resulted in a unit weighing 1.5 pounds and measuring $3^1/_2$ by $2^3/_4$ by $2^3/_4$ inches. This balancer has an efficiency of 96 per cent at rated load and will supply this load continuously with a temperature rise of 40 degrees centigrade at sea level. The voltage unbalance of the inverter at rated single-phase load is negligible when the balancer is used. It consists of a tapped reactor and a capacitor connected to the line as in Figure 2.

Figure 1. The unit described in this paper rated 265 volt-amperes, 115 volts, 94 per cent power factor, 400 cycles

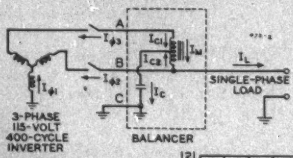


Figure 2. Schematic connection diagram for the balancer unit

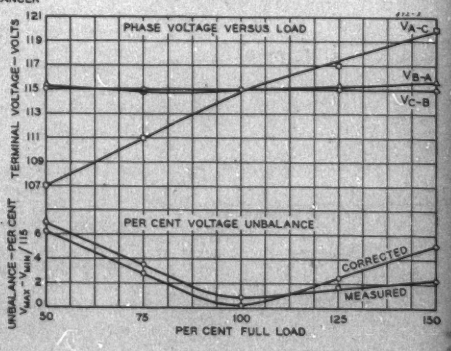


Figure 3. Voltage unbalance of the power supply under conditions of varying single-phase load. Balancer unit connected

Performance

The three-to-one phase balancer is designed for a particular single-phase load and will function ideally only at this load. Figure 3 illustrates this point. This characteristic of the balancer makes it advisable to incorporate the unit as part of the load and connect it to the power supply when the single-phase load is applied.

All of the accompanying data were taken using a Holtzer-Cabot inverter having the rating mentioned above for the three-phase output circuit. The inverter used had an initial voltage un-

Paper 44-72, recommended by the AIEE committee on air transportation for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19–20, 1944. Manuscript submitted February 1, 1944; made available for printing March 2, 1944.

SYDNEY WIMPIE is engineer, Holtzer-Cabot Electric Company, Boston, Mass.

Acknowledgment is made to R. W. Matthews of the Holtzer-Cabot Electric Company for his assistance in preparing data for this paper.

smaller importance as the number of tubes (phases) in the rectifier is increased.

6. Multiphase rectifiers appear to have definite electrical and mechanical advantages which will offset their increased cost and size.

7. Designs of machines must be altered to take account of current, torque, and flux pulsations superimposed on conventional d-c values.

References

1. THYRATRON CONTROL OF D-C MOTORS, G. W. Garman. AIEE TRANSACTIONS, volume 57, 1938, July section, pages 335–42.

2. THYRATRON MOTOR CONTROL, E. E. Moyer and H. L. Palmer. AIEE TRANSACTIONS, volume 62, 1943, November section, pages 707–11.

3. ELECTRONIC CONTROL OF D-C MOTORS, K. P. Puchlowski. AIEE TRANSACTIONS, volume 62, 1943, pages 870–7.

4. THEORY OF RECTIFIER—D-C MOTOR DRIVE, E. H. Vedder and K. P. Puchlowski. AIEE TRANSACTIONS, volume 62, 1943, pages 863–70.

5. INVERTER ACTION ON REVERSING OF THYRATRON-MOTOR CONTROL, H. L. Palmer and H. H. Leigh. AIEE TRANSACTIONS, volume 63, 1944, April section, pages 175–84.

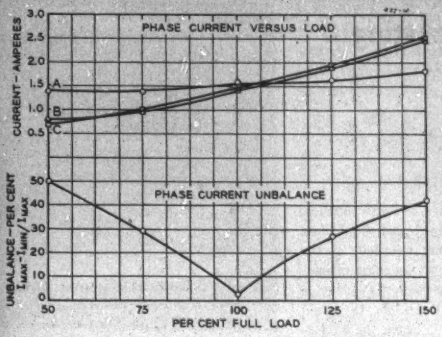
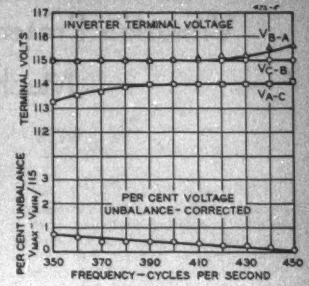


Figure 4 (left). Phase-current unbalance of the power supply under conditions of varying single-phase load. Balancer unit connected

Figure 5 (right). Voltage unbalance of the power supply versus frequency. Balancer unit connected

Figure 6 (below). Phase-current unbalance of the power supply versus frequency. Balancer unit connected



balance of 0.8 volt at no load. The curves marked "corrected" have been compensated for this unbalance.

Since the unbalance of terminal voltage with unbalanced load is a function of the inverter, curves of phase-current unbalance have also been plotted to give a clearer picture of the behavior of the balancer.

The voltage across the load was kept constant at 115 volts so that the data would not be confused by the regulation of the inverter.

For the purpose of comparison, the performance of the inverter alone is given. At 100 per cent single-phase load on terminals *B* and *C*, with no balancer, the inverter voltages were unbalanced 7.65 per cent. The readings were:

V_{C-B}	V_{B-A}	V_{A-C}
115.0 volts	116.0 volts	123.8 volts

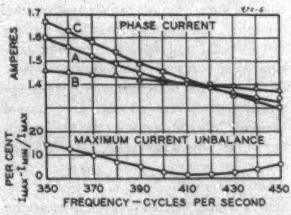
The frequency response of the balancer is also shown (Figures 5 and 6). It can be seen from these curves that the unit operates reasonably well over a wide range of frequencies, so that the value of the unit is not impaired by the speed regulation of the power supply.

Conclusion

The unit described is suitable for aircraft use due to its small size, light weight, and high efficiency. It has the added advantage of improving the power factor in the lines to 0.866 in those cases where the single-phase load is less than this value. Additional tests prove the unit will function at temperatures and pressures encountered at high altitudes.

Appendix

The operation of the balancer can be understood by referring to the vector diagram of Figure 7. The single-phase load is connected across terminals *B* and *C* of the inverter. The balancer is connected so that the reactor is across phases *A* and *B* and the free end of the capacitor is connected to terminal *C*. Phase rotation is *A–B–C*.



The value of the capacitor and the reactor needed to balance any single-phase load as well as the position of the reactor tap, can be obtained by referring to the schematic wiring diagram (Figure 2) and the vector diagram (Figure 7). The vector diagram is drawn to represent balanced conditions.

From Figure 2:

$$I_{\phi 1} = I_L + I_C \tag{1}$$

$$I_{\phi 2} = I_M - I_{C2} - I_L \tag{2}$$

$$I_{\phi 3} = -I_{C1} - I_M \tag{3}$$

Under balanced conditions

$$I_{\phi 1} = I_{\phi 2}/\underline{120°} = I_{\phi 3}/\underline{120°} \tag{4}$$

and

$$V_{OC} = V_{OB}/\underline{120°} = V_{OA}/\underline{120°} \tag{5}$$

Assuming no power lost in the balancer and the phase currents in phase with the terminal-to-terminal voltages (a condition found necessary to obtain balance), the power supplied by the inverter must equal the power absorbed by the single-phase load.

$$3E_\phi I_\phi \cos 30° = E_L I_L \cos\theta \tag{6}$$

or

$$\sqrt{3}E_L I_\phi \times 0.866 = E_L I_L \cos\theta \tag{7}$$

and

$$I_\phi = {}^1/_3 I_L \cos\theta \tag{8}$$

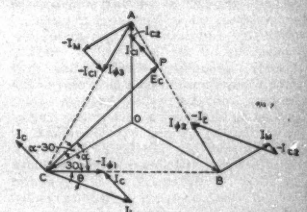


Figure 7. Vector diagram of the unit

From equation 1

$$I_C = I_{\phi 1} - I_L \tag{9}$$

The angle of the voltage across the capacitor is assumed 90 degrees lagging the capacitor current. The absolute value of capacitor voltage is:

$$/E_{CP}/ = (115 \sin 60°)/\sin(60+\alpha) \tag{10}$$

and the voltage E_{BP} across the lower part of the reactor is

$$/E_{BP}/ = (115 \sin \alpha)/\sin(60+\alpha) \tag{11}$$

Making use of the superposition theorem, the net current through the reactor can be considered as being made up of the reactor magnetizing current I_M, a part of the capacitor current I_{C2} flowing between the reactor tap and terminal *B*, and the remainder of the capacitor current I_{C1} flowing between the tap and terminal *A*. It can further be seen that if the internal impedance of the power supply is small compared to the impedance of the load

$$I_{C1}/I_{C2} = E_{BP}/E_{PA} \tag{12}$$

The reactor magnetizing current is, from equation 2,

$$I_M = I_L + I_{C2} + I_\phi \tag{13}$$

The balancer described in the beginning of this article consisted of a four-microfarad capacitor and a reactor drawing a magnetizing current of 1.41 amperes tapped at 33.6 volts from the *A* terminal.

Reference

1. Letters to editor, *Electrical World*, December 26, 1942.

Vibration Protection for Rotating Machinery

R. L. WEBB
MEMBER AIEE

C. S. MURRAY
ASSOCIATE AIEE

Synopsis: Vibration protection becomes desirable for rotating machinery when it is operated with certain defects. Electric generators may be operated with a single "ground" on the rotating field circuit without harm but the potential hazards of a second "ground" at another point on the same circuit are so great that the need of protective equipment for automatic disconnection of the generator is evident. Double "grounds" on a rotating field circuit may short-circuit a large part of the winding, unbalance the magnetic field, and set up vibrations of such serious magnitudes that the machine may be wrecked.

A method for obtaining satisfactory vibration protection for rotating machines has been developed. It uses equipment most of which is already on hand or readily available to most companies operating important machinery. The only part requiring construction is an electronic amplifier.

The equipment, its operating characteristics, wiring, and performance are described in this paper.

The described protective equipment has been in service on one machine since the latter part of 1942. It has given entirely satisfactory service. Another machine was protected in a similar manner for about three months until it was found convenient to rewind the field.

ROTATING machinery of all types is subject to damage when exposed to severe vibration caused by mechanical unbalance, or its equivalent, in the rotating element. Although electrical machinery has a good record in this respect, its freedom from vibration has been due largely to the degree of maintenance which it usually receives. Now, however, due to wartime restrictions, electrical and other machinery is often run under conditions which would not be permitted normally until after repairs had been made. When this is done, protective measures should be adopted where possible to prevent serious machine damages if the weakened part should fail.

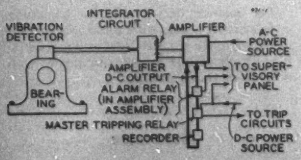


Figure 1. Schematic arrangement of vibration protection equipment

One expedient being adopted, as the occasion demands, is to continue operating a-c synchronous machinery after a "ground" has developed in the field winding of the rotor. Since the excitation system is operated ungrounded normally, the winding-to-ground fault is not harmful and does not prevent continued and normal machine operation. Such operation does, however, expose the machine to severe damage if a second "ground" should occur in the field winding or at any other place on the same excitation system. Two "grounds" may effectively short-circuit a portion of the field winding, thereby causing magnetic unbalance in the rotor. If a large portion of the field winding is short-circuited by the second "ground," the field current in the remainder of the winding will increase and further aggravate the unbalanced magnetic condition. Cases are on record of double "grounds" in field windings which have caused such severe vibration that the bearing pedestals were broken allowing the rotating field to drop on the stator laminations. Such failures have, in each known case, caused damages which required costly repairs and long machine outages.

A protective method, that detects excessive vibration, has been developed by engineers of the Consolidated Edison Company of New York. It operates relays which function quickly to initiate the circuit breaker operations required to relieve the condition. In the case of synchronous machinery the a-c armature and d-c field breakers are opened as fast as possible and, if desired, the prime mover power may be shut off. Other types of machinery would be handled as conditions and equipment permit.

Protective System

The protective system consists of the following parts:

1. Seismographic type vibration detector.
2. Integrator circuit.
3. Resistance coupled amplifier.
4. Alarm and protective relays.
5. Vibration recorder.
6. Supervisory circuits.

Figure 2. Seismographic vibration detector with cover removed

The arrangement of these parts is shown schematically in Figure 1. An alternating voltage is generated by the vibration detector when vibration is present in the part on which it is mounted. This voltage is impressed, through an integrator circuit, to an amplifier. The current is amplified and then rectified before being passed through the relays and the recorder. The system is provided with various features which prevent incorrect performance of the relays due to wire failure, tube failure, and loss of a-c or d-c power supply.

Vibration Detector

The vibration detector was one originally furnished by its manufacturer for use in connection with vibration recorders. It is constructed on the seismograph principle, with a strong permanent magnet supported on springs serving as the stationary element. A light coil supported to the base of the detector is free to move in the magnetic field when the base of the detector is subjected to vibration. The base of the detector is mounted rigidly on the bearing or other part whose vibration is to be measured. The detector is inherently a velocity measuring device since the alternating voltage it generates is directly proportional to vibration frequency and to vibration amplitude for sinusoidal vibration.

The detector is shown without its cover in Figure 2. Figure 3 shows two detectors mounted on a generator-outboard-bearing cap. Generator-bearing pedestals

Paper 44-71, recommended by the AIEE committees on power generation and protective devices for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19–20, 1944. Manuscript submitted February 9, 1944; made available for printing February 29, 1944.

R. L. WEBB is assistant engineer, electrical engineering department, and C. S. MURRAY is junior engineer, Consolidated Edison Company of New York, Inc., New York, N. Y.

Figure 3. Vibration detectors mounted on turbogenerator bearing

are frequently insulated from the supporting bedplate of the machine. Care should therefore be exercised to prevent short-circuiting this insulation when installing metallic conduit for connection to the detector device mounted on the bearing cap. The detector mounting must be rigid enough to avoid resonant vibration in the detector supports. Since the wiring from the detector to the amplifier requires protection against induced voltages, twisted and shielded conductors are used. It is also preferable to have them routed remotely from other circuits carrying alternating current or impulse currents.

Integrator Circuit

Since it is desired to operate the protective relay on vibration amplitude only, it is necessary to interpose an integrator circuit between the detector and the amplifier. On the installation being described, this circuit consists of a 19,000-ohm resistor in series with a three-microfarad capacitor. The output from the detector is connected across the complete circuit while the voltage drop across the capacitor is wired to the amplifier and is used to govern the operation of the relays. The resistance of the circuit predominates over the capacitance, except at very low frequencies, hence the current in the circuit remains nearly constant with the same impressed voltage for any frequency of vibration at which protection is desired. Since for a given vibration amplitude the voltage generated in the detector is directly proportional to frequency while the capacitive reactance of the capacitor is inversely proportional to frequency it follows that the voltage drop across the capacitor does not change with different frequencies and is therefore proportional to vibration amplitude alone. The output voltage E_2 of the integrator circuit may be calculated for any input voltage E_1 and frequency f by use of the formula:

$$E_2 = \frac{E_1}{(19{,}000^2 + X^2_c)^{1/2}}$$

where

$$X_c = \frac{10^6}{2\pi f \times 3}$$

The circuit produces a voltage output nearly proportional to vibration amplitude over a wide frequency range. One curve of Figure 4 shows the degree of accuracy obtained with the circuit. At 30 cycles per second and above the error is negligible. At five cycles per second the output of the circuit is about 12 per cent low. Five cycles per second corresponds to about 16 per cent of rated speed for this machine.

Amplifier

The amplifier is resistance coupled so that it also will provide good accuracy over a wide frequency range, and particularly at the lower vibration frequencies. The degree of accuracy obtained in the amplifier at different frequencies is shown by the other curve of Figure 4. Reasonably good accuracy at low frequencies is desired to provide satisfactory vibration protection while machines are being brought up to speed or slowed down after a run. An over-all error of 15 per cent at five cycles per second, 12 per cent for the integrator circuit, and 3 per cent for the amplifier, is considered satisfactory for the protective relays since damage due to vibration is not likely to be severe at lower speeds. Some generators, such as cross-compound units, must have their field windings energized at the time of start-up and would, therefore, be subject to vibration due to double field "grounds" even at moderate speeds.

The over-all voltage amplification of the amplifier is about 1,700. Its response is linear from zero to 16 millivolts input from the integrator. The d-c load circuit resistance is 1,700 ohms. At 20 milliamperes, the output of the amplifier is 34 volts direct current and 0.68 watt.

Three stages are used in the amplifying circuit, two stages being obtained in two double-triode tubes and a third stage being obtained in two triode tubes connected in push-pull arrangement. To prevent incorrect relay operation in case of electron-tube failure, the filament circuits of the various stages are connected in series with an instantaneous overcurrent relay. When the filament current is reduced due to any filament failure the relay operates to open the output circuit of the amplifier and to close a signal circuit. Such operation makes the protective relays inoperative and starts a supervisory lamp flashing at a point where it will attract the attention of the operators.

The amplifier output is rectified by a copper-oxide bridge circuit and the direct current from the rectifier is wired to the relays, and to the recorder, if used.

Figure 5 shows a schematic diagram of the amplifier connections and associated equipment. The over-all calibration of the vibration-protection equipment including the detector unit, integrator, and amplifier is given in Figure 6. To obtain this calibration initially the detector was caused to vibrate and its double amplitude of vibration in mils was measured with a portable Starrett type vibrometer. The range of d-c output current as obtained from the amplifier for various values of vibration is entirely suitable for relay application. It is not practicable to check the over-all calibration (d-c output current versus mils vibration) each time the amplifier and relay equipment require calibrating. Since there are occasions when the amplifier must be recalibrated (when tubes are changed or when other parts are replaced) a 60-cycle calibration curve was obtained following the initial over-all calibration. This curve is also given in Figure 6. The calibration curve was obtained by impressing 60-cycle voltages across the same input terminals to which the output of the detector is connected. This calibrating curve assists not only with adjustments to the amplifier and relays but permits a complete check on the accuracy of the recorder, as required.

It will be noted on Figure 5 that the amplifier circuits are grounded through a 0.5-megohm resistor. This resistance is intended to prevent incorrect operation of the relays in case a wire "ground" should develop in the detector output circuit at a point where the "ground" potential is operating at a small voltage difference

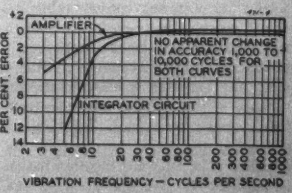


Figure 4. Accuracy curves for integrator and amplifier versus vibration frequency

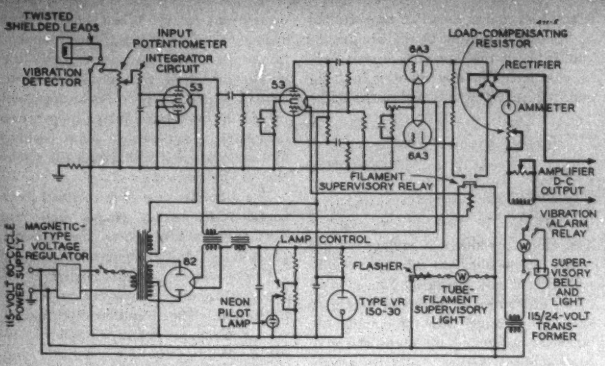


Figure 5. Connection diagram for amplifier and associated equipment

with respect to the "ground" bus potential at the amplifier. A potential of about one volt at 60 cycles between the two wires from the detector is sufficient to cause operation of the master tripping relay.

Relays

A diagram of relay connections is given on Figure 7. Two "lock-out" relays are used, one being an a-c undervoltage relay and the other a d-c undervoltage relay. These undervoltage "lock-out" relays open the tripping circuit instantly if either source of power is lost. The a-c relay will reset about one minute after restoration of voltage which allows ample time for the tubes of the amplifier to become heated and its output current to become steady before the equipment is returned to service. The d-c undervoltage relay resets in about 10 seconds after voltage is restored, this time allowing for the master tripping relay element to come to its stable position after its field coil is energized.

The alarm overcurrent relay is a simple hinged armature device equipped with a variable resistor connected in parallel with its coil to provide means for adjusting its operating current value. A second resistor is connected in series with the relay circuit to permit readjustment of the over-all series-circuit resistance when any variation is made in the resistance in parallel with this relay coil. This permits retaining a constant resistance in the output circuits from the rectifier. The relay for this installation is adjusted to give an alarm to the operators at eight mils vibration.

The master tripping relay has a

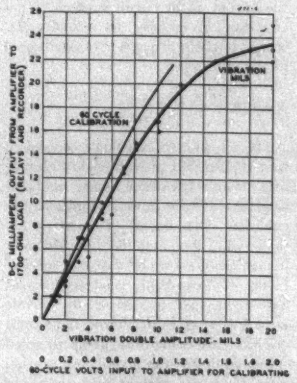

D-C MILLIAMPERE OUTPUT FROM AMPLIFIER TO 1750-OHM LOAD (RELAYS AND RECORDER)
60 CYCLE CALIBRATION
VIBRATION MILS
VIBRATION DOUBLE AMPLITUDE - MILS
60-CYCLE VOLTS INPUT TO AMPLIFIER FOR CALIBRATING

Figure 6. Characteristic output curves of amplifier

standard d'Arsonval type element with a field coil. Its field coil is connected to a separate d-c power supply. The d-c output from the rectifier is passed through the moving coil of the relay. Since the moving element is restrained by a small spiral spring the element changes its position to follow any increase of vibration. Adjustment is made by changing the position of the stationary contact so as to require more or less travel of the moving element against the restraining spring. Since the relay moves to follow any change in vibration almost instantly, it will be in position to trip shortly after the machine vibration reaches the value for which the relay is set to operate. The master tripping relay trips the main generator breakers and the field breakers when the bearing vibration reaches 12 mils.

Any d-c relay which will operate over the range of current shown in Figure 6 would be suitable for the master tripping relay. Of course the vibration scale can be contracted or expanded on Figure 6 by simply varying the potentiometer adjustment at the input to the integrator. The relay used should be fast to prevent an excessive overswing of the vibration before the tripping relay operates.

The relays become inoperative but do not operate incorrectly due to the following troubles: (1) open-circuited or short-circuited wires from the vibration detector, (2) failure of electron tubes, (3) interruption of a-c or d-c power supply, (4) relay failure, or (5) tripping-circuit failure. Complete supervision is provided to the operators for conditions (2), (3), and (5).

Figure 8 shows the relay panel with the amplifier at the top. It will be noted that two complete protective equipments are provided. The two corresponding vibration detectors are shown in Figure 3. On this installation two complete protective equipments were installed with separate power sources and tripping circuits to provide a high degree of reliability. In case any part of one equipment develops trouble the second equipment will provide complete vibration

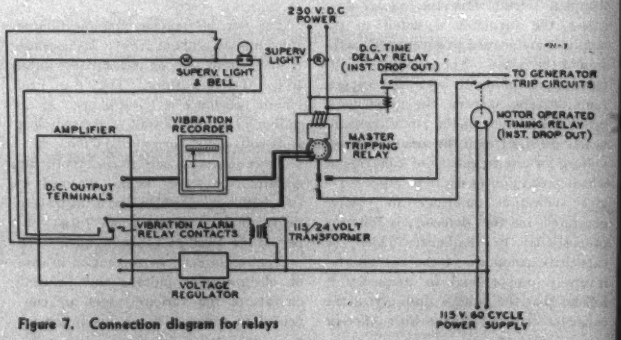


Figure 7. Connection diagram for relays

protection since all of its parts function independently. Since this particular generator is one of the largest on the system it was decided that the unit should not be run at any time without at least one vibration protective equipment in service. Two equipments have the advantages of permitting tube changes and calibration work on the parts of one without having to take the main generator out of service and they provide a continuous check on the accuracy of each other.

Vibration Recorder

A recorder may or may not be used in such a circuit but on the installation being described a recorder is found useful and it is inserted in series with the d-c output from the rectifier. The instrument is located near the turbine to permit continuous supervision of the bearing vibration by the turbine engineer. A continuous record is obtained of bearing vibration in a manner not feasible with indicating instruments. Samples of such records when starting, when running, and when shutting down are shown in Figure 9. The recorder instrument is an ordinary low range d-c milliammeter.

Supervisory Circuits

A supervisory panel for the equipment may be located at any convenient point. In the installation being described this panel is placed above the main control panel for the generator. There are four signals:

The first is an alarm and a light operated by the vibration alarm relay at 8 mils vibration.

The second signal is a light which is normally energized. It starts to flash when an electron-tube filament burns out. Such action is initiated by the undercurrent relay which is in series with the amplifier filament circuit. Loss of filament current makes the protection inoperative.

The third signal is a light which is normally energized and which becomes dark when the d-c power supply is interrupted. In this installation, the d-c power is used only for polarizing the master protective relay, hence, loss of that supply makes the protective equipment inoperative.

The fourth signal is the lights of the first and second signal both of which become dark when the a-c power supply is interrupted. Loss of a-c power deenergizes the amplifier and makes the protective equipment inoperative.

Operating Experience

No uncontrolled or accidental outage of the equipment has occurred since it

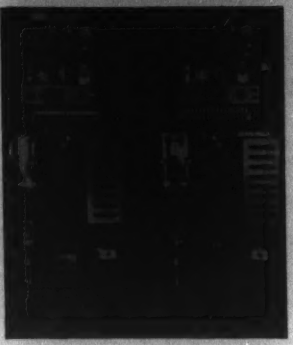


Figure 8. Vibration protection relay panels

was placed in operation in October 1942. It has not been called upon to disconnect the generator automatically since no severe vibration has occurred.

On one occasion a momentary "ground" occurred on one of the wires that connect to the vibration detector. Since the "ground" potential at that point was slightly different from the "ground" potential where the amplifier was mounted, this voltage difference, being impressed on the first stage of the amplifier, caused a surge of direct current to the relays and recorder. The recorder swung up-scale and the vibration alarm relay operated but the "ground" did not remain on the wire long enough for the master tripping relay to operate. The 0.5-megohm resistor was then connected in the "ground" circuit at the amplifier to prevent incorrect tripping due to an accidental "ground."

When first installed the vibration alarm relay was adjusted to operate at six mils vibration. It was found that the relay would operate occasionally as the generator was passing through its critical speed on starting or shutting down operations. The relay was readjusted to operate at eight mils vibration and no further relay operations of this type have been reported.

On two or three occasions the vibration alarm relay has operated and reset as the generator load was being increased. It was found that the machine experienced abnormal vibration of short duration as some of the steam valves are opened to increase the power output of the turbine. This behavior does not occur each time the load is brought up on the machine, in fact its occurrence is more "the exception" than "the rule."

Maintenance

Maintenance on the vibration protective equipment may be made to fit in with maintenance on other generator protective relays. The amplifier, relays and recorder should be calibrated on the same schedule with generator differential relays.

The amplifier tubes should be replaced every three to six months assuming they are in service continuously. The replacement tubes for the push-pull stage should be selected for balance before being installed.

The vibration detector should be inspected at times when the machine is shut down to determine whether any parts have become loose; once a month is often enough.

The usual attention to paper and ink must be given the recorder.

Conclusions

1. A simple scheme is made available for suitable and fast vibration protection for rotating machinery.

2. The protective scheme provides suitable protection against magnetic unbalances as well as against mechanical unbalance in rotating elements.

3. The equipment described has been in service since 1942 and has given a record of reliability entirely satisfactory for large turbogenerator protection.

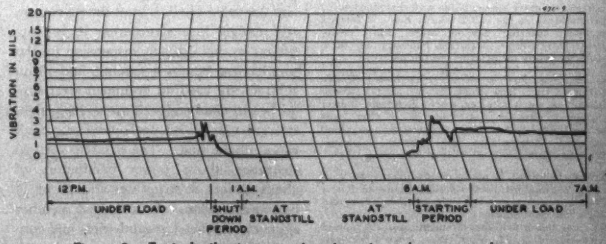


Figure 9. Typical vibration recorder charts for turbogenerator bearing

Measured Electrical Constants of 270-Mile 154-Kv Transmission Line

C. A. STREIFUS
MEMBER AIEE

C. S. ROADHOUSE
NONMEMBER AIEE

R. B. GOW
ASSOCIATE AIEE

Synopsis: Results of measurements are presented of fundamental electrical constants of a 270-mile 154-kv transmission line. Comparisons are made between values obtained from test and those obtained from circuit dimensions and computations, thus providing a check on some conventional methods of determining basic line impedance and admittance units. Included are unit resistance, inductive reactance, and capacitive susceptance together with *ABCD* constants and characteristic impedance of positive-phase sequence, zero-phase sequence, and one-conductor-and-ground long-line networks.

PART of results obtained from measurement of electrical constants of long transmission line have been presented previously.[1] Interest shown in these measurements and request for additional information led to this more complete presentation of data and results of tests which will be of interest to engineers who follow long-transmission-line theory and practice, relay application, and fault studies.

Engineers desire to check theory behind development of formulas and constants by actual measurement. Thus theoretical procedures which may include many factors and assumptions might be replaced, if possible, by more simple methods. Check measurements of zero-phase-sequence impedances especially are desirable, because calculations for these include effect of indefinite factors, such as, average distance between shield wires and conductors, their average height above ground, effect of earth-resistivity and reactance, and variations in construction from the straight-line structure. To a lesser degree perhaps, a check of positive-sequence values is also desirable to determine importance of assumptions used in theoretical calculations.

Since new-type impedance relays described previously[2,3] were being applied, and since accurate basic data for determining normal and short-circuit conditions were desired for satisfactory operation and protection, measurements of unit values were made upon completion of line but before it was placed in operation. These data obtained from measurements, also provided information to check relay settings previously computed from theoretical sources.

Specific methods of determining line constants are not recommended and a comparison between methods of computation is not made, but rather the paper is intended to present simply results of field measurements and to compare these with values obtained through some conventional procedures.

Line Construction

Typical structure used on straight-line construction is shown in Figure 1. Figure 2 gives average spacing and configuration of conductors and shield wires. Horizontal distances are same as those at typical straight-line structure and vertical distances are assumed as average considering that sag of shield wires is less than sag of conductor. Line is 268.52 miles long without intermediate switching stations or taps. Ruling span is 600 feet. It is single-circuit of wood-pole H-frame construction with horizontal conductor spacing of 14 feet 6 inches. Conductor is 0.683 inch in diameter and is 250,000 circular mils of hollow hard-drawn copper. At straight-line structures, it is supported by ten 10-inch suspension insulators having $5^3/_4$-inch spacing, and 15 insulators are used on grounded steel supports and dead ends. Two $^3/_8$-inch high-strength galvanized-steel overhead ground wires shield line. These have vertical clearance above power conductors of about 10 feet at structures and about 18 feet at mid-span. A steel cross member supports overhead ground wires and connects these to both pole grounds at each

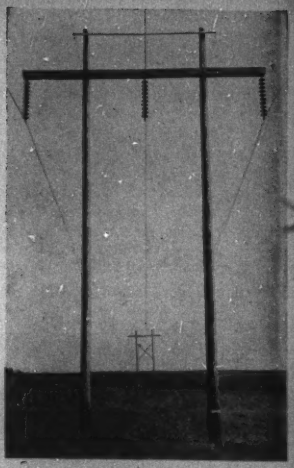


Figure 1. Typical structure, 154-kv line

structure. Pole ground is number 6 steel wire carried down pole and wrapped around base. There are no counterpoises on line. Shield wires are connected to station grounds at terminals. There are three complete transposition barrels in line.

Test Procedure and Conditions

Measurements were made by applying potential from 2,400/4,160-volt 60-cycle source supplied from three 50-kva 13,800–2,400/4,160-volt Y-connected transformers at one terminal with conductors at other end appropriately connected for six short- and open-circuit tests listed in Table I. Portable ammeters, voltmeters, and wattmeters of good quality and recent calibration were used with outdoor instrument-type current and potential transformers at terminal at which potential was applied. Similarly ammeters and voltmeters were used at opposite terminal. All measurements include impedance of carrier-current wave traps

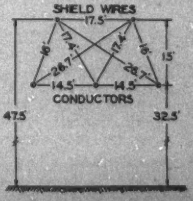


Figure 2. Conductor and shield-wire configuration. Approximate average spacings and heights above ground are shown

Paper 44-80, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE North Eastern District technical meeting, Boston, Mass., April 19-20, 1944. Manuscript submitted February 19, 1944; made available for printing March 16, 1944.

C. A. STREIFUS is electrical engineer, Ebasco Services, Inc., New York, N. Y.; C. S. ROADHOUSE is substation engineer, Nebraska Power Company, Omaha, Neb.; and R. B. GOW, now in the United States Navy, formerly was electrical engineer, Kansas Gas and Electric Company, Wichita, Kan.

Acknowledgment is made of the participation of L. E. Wallingford, formerly with Nebraska Power Company and now in the United States Navy, and W. A. Wolfe of Kansas Gas and Electric Company, who assisted in field measurements, and the helpful criticisms of D. M. MacGregor, Ebasco Services, Inc., who reviewed the paper.

which were in service as part of the communication system used throughout tests, but 60-cycle effect of these was negligible. Atmospheric temperature during five or six hours of testing ranged from 75 to 90 degrees Fahrenheit with perhaps 85 degrees as an average value.

Phase rotation of terminal systems was also compared using a phase-sequence instrument and found to check transposition plan. This was later confirmed when systems were synchronized first time. Open- and short-circuit impedances, ***ABCD*** constants, unit impedance and admittance values, and characteristic impedances were calculated from instrument readings of amperes, volts, and watts as discussed in Appendix I.

Summary of Results

Tables I to VII, inclusive, summarize data taken during tests; compare line constants obtained from these data with those obtained from computations; and list other related information. For brevity, word "measured" applies to values obtained through supplementary calculations from test data, and word "computed" applies to values obtained from references or from computations based on physical dimensions of line and on conductor and shield wire configuration. In following discussions, "reactance" refers to inductive reactance, and "susceptance" refers to capacitive susceptance. Symbols are explained in Appendix VI.

Table I lists impedances as viewed from instruments with conductors at other end open- or short-circuited to ground and as obtained from supplementary calculations using data from ammeter, voltmeter, and wattmeter readings. Also included are computed values of open- and short-circuit impedances obtained from ***ABCD*** constants in Tables II, III, and IV. Tests *A* and *B*, *C* and *D*, *E* and *F* give basic data for positive-phase sequence, zero-phase sequence, and one-conductor-and-ground networks, respectively. Test *B* was repeated with conductors short-circuited together at far end but not grounded. Instrument readings were same as before. There was no potential between short-circuited conductors and ground, indicating balanced impedance of conductors.

Table II indicates that positive-phase-sequence values of resistance and reactance are higher than computed values with susceptance being slightly smaller. Difference between measured and computed values may be result of not taking into account effect of ground and shield wires in conventional computations and of angles in line and other factors causing departure from uniform construction. Characteristic impedance of 409 ohms is near 400-ohm value commonly accepted.

Table III shows that measured zero-phase-sequence resistance and reactance unit values are smaller than computed values which are based on small current flow of one or two amperes in shield wires believed to be comparable to that flowing during tests. During fault conditions, currents are high causing some change in resistance and reactance of shield wires. Assuming 40 amperes flowing in each shield wire, computed unit values are: $r_0 = 0.696$ and $x_0 = 2.44$. Susceptance values are same, possibly due to rather complete method of calculating referred to in Appendix V.

Table IV values for a one-conductor-and-ground circuit are of interest although they are not actually used in conventional high-voltage-transmission-line and system-fault calculations. Measured unit resistance is lower than computed. Reactance and susceptance values compare favorably. Computed values of resistance and reactance in this case, also depend on amount of current assumed flowing in shield wires. Of course, comparatively small currents flowed during measurements. Computed values listed assume about one or two amperes flowing. With 40 amperes assumed in each shield wire, computed unit resistance and reactance values are: $r_1 = 0.389$ and $x_1 = 1.35$. Characteristic impedance of 550 ohms measured at 60 cycles is of interest and compares with 500-ohm value commonly used for a single-wire and ground circuit and in design of lightning-proof lines. One-conductor-and-ground circuit measured forms part of carrier-current channel.

Table V summarizes characteristic impedances obtained from data taken during tests.

Table VI gives important ratios. Those obtained from measured data are lower except ratio of susceptances which are nearly equal.

Table VII gives ratios of sending-to-receiving current and voltages for the several tests. It will be noted that reciprocal of voltage rise ratios in tests *A*,

Table I. Summary of Tests and Impedance Data

Test Description	Test	Measured Impedances in Ohms as Viewed From Instruments: Symbol	R	$+jX_L$ or $-jX_C$	Z/θ	Computed
Balanced three-phase potential applied to three conductors with them open at other end	*A*	$Z_{ocp} = \frac{A_p}{C_p}$	21.2	$-j648$	648/88.13	646/88.03
Balanced three-phase potential applied to three conductors with them shorted and grounded at other end	*B*	$Z_{scp} = \frac{B_p}{A_p}$	85.8	$+j243$	258/70.6	251/71.48
Single-phase potential applied between all three conductors and ground with them tied together and not grounded at other end	*C*	$\frac{Z_{oc0}}{3} = \frac{A_0}{3C_0}$	21.2	$-j273$	275/85.6	270/84.29
Single-phase potential applied between all three conductors and ground with them tied together and grounded at other end	*D*	$\frac{Z_{sc0}}{3} = \frac{B_0}{3A_0}$	88.2	$+j232$	247/69.1	275/64.39
Single-phase potential applied between one conductor and ground with it not grounded at other end	*E*	$Z_{oct} = \frac{A_1}{C_1}$	34	$-j707$	707/87.25	695/86.53
Single-phase potential applied between one conductor and ground with it grounded at other end	*F*	$Z_{sct} = \frac{B_1}{A_1}$	150	$+j399$	426/69.4	430/67.9

Table II. Positive-Phase-Sequence Constants

$A_pB_pC_pD_p$ Constants	A_p	B_p	C_p
Measured	0.853/3.19	220/73.79 ohms	0.001316/91.32
Computed	0.854/2.84	214/74.32 ohms	0.001332/90.87

Per mile values	Resistance r_p, Ohms	Inductive Reactance jx_p, Ohms	Capacitive Susceptance jb_p, Micrombos
Measured	0.254 @ test temp.	j0.823	j5.14
Computed	0.238 @ 25 deg C.	j0.803	j5.18

Characteristic impedance	$\sqrt{Z_{ocp} \times Z_{scp}}$	$\sqrt{Z_p/Y_p}$	$\sqrt{z_p/y_p}$	$\sqrt{\frac{A_pB_p}{C_pD_p}}$
Measured	409/8.77	409/8.58	409/8.58	409/8.77
Computed	403/8.28	403/8.25	403/8.25	403/8.28

Table III. Zero-Phase-Sequence Constants

$A_0B_0C_0D_0$ Constants	A_0	B_0	C_0
Measured	0.735/6	545/75.1 ohms	0.000892/91.6
Computed	0.716/7.88	591/72.27 ohms	0.000885/92.17

Per mile values	Resistance r_0, Ohms	Inductive Reactance jx_0, Ohms	Capacitive Susceptance jb_0, Micromhos
Measured	0.636 @ test temp.	$j2.14$	$j3.65$
Computed	0.829 @ 25 deg C.	$j2.28$	$j3.65$

Characteristic Impedance	$\sqrt{Z_{oco} \times Z_{oco}}$	$\sqrt{Z_0/Y_0}$	$\sqrt{z_0/y_0}$	$\sqrt{\frac{A_0B_0}{C_0D_0}}$
Measured	783/8.25	782/8.28	782/8.28	783/8.25
Computed	816/9.95	816/9.95	816/9.95	816/9.95

Table IV. Constants of One-Conductor-and-Ground Circuit

$A_1B_1C_1D_1$ Constants	A_1	B_1	C_1
Measured	0.798/4.39	340/73.79 ohms	0.001130/91.64
Computed	0.795/4.9	342/72.8 ohms	0.001145/91.43

Per mile values	Resistance r_1, Ohms	Inductive Reactance jx_1, Ohms	Capacitive Susceptance jb_1, Micromhos
Measured	0.408 @ test temp.	$j1.295$	$j4.46$
Computed	0.438 @ 25 deg C.	$j1.3$	$j4.6$

Characteristic Impedance	$\sqrt{Z_{oc1} \times Z_{oc1}}$	$\sqrt{Z_1/Y_1}$	$\sqrt{z_1/y_1}$	$\sqrt{\frac{A_1B_1}{C_1D_1}}$
Measured	550/8.93	551/8.75	551/8.75	550/8.93
Computed	548/9.32	547/9.32	547/9.32	548/9.32

C, and E, in which far-end conductors were not grounded, check very closely with the A constant as they theoretically should do for that particular arrangement of conductors. Reciprocal of current rise ratio of test B closely gives A constant. In this test conductors were tied together at far end and grounded, but as mentioned above, grounding had no effect on impedances measured. Also no current flowed through earth. However, reciprocal of current rise ratios in tests D and F do not give accurately the A constant. In tests D and F, conductors were grounded and current returned through ground and shield wires. This would indicate that unit values, particularly resistance and reactance, are slightly different for conditions with conductors grounded and not grounded in zero-phase sequence and one-conductor-and-ground circuit networks.

With no potential applied there was no indication of induced voltage on line when measured by potential transformers and voltmeters. During attenuation tests at carrier frequencies a two- or three-volt potential was observed between one conductor and ground using a vacuum-tube voltmeter shunted by 550-ohm resistor, indicating that any induced voltage effects were small. During test E in which 2,400 volts to ground was applied to one conductor only, potential between other two conductors and ground measured at far end was 300 volts. There was no appreciable unbalance of reactance between the three conductors as shown by three line-to-neutral impedance values of 257.5, 257.5, and 258 ohms which were computed using three-phase values taken during test B.

Table V. Summary of Characteristic or Surge Impedances

	Measured	Computed
From positive-phase sequence data. Conductor-to-conductor or conductor - to - equivalent neutral	409/8.77	403/8.28
From data taken with all three conductors tied together. Characteristic impedance between three conductors tied together and ground	261/8.25	272/9.95
Zero-phase-sequence characteristic impedance or three times preceding values	783/8.25	816/9.95
For one-conductor-and-ground circuit	550/8.93	548/9.32

Table VI. Ratios of Zero-Phase- to Positive-Phase-Sequence Resistance, Inductive Reactance, Impedance, and Capacitive Susceptance

	r_0/r_p	x_0/x_p	Z_0/Z_p	b_0/b_p
Measured	2.51	2.6	2.58	0.71
Computed	3.48	2.84	2.88	0.705

Table VII. Current and Voltage Rise or Increase

Test	Rise: Current or Voltage at Energizing End Divided Into Values at Other End
A...Balanced three-phase potential applied to all three conductors with them open at other end	Voltage—1.18
B...Balanced three-phase potential applied to all three conductors with them short-circuited and grounded at other end	Current—1.2
C...Single-phase potential applied between all three conductors and ground with them tied together and ungrounded at other end	Voltage—1.36
D...Single-phase potential applied between all three conductors and ground with them tied together and grounded at other end	Current—1.4
E...Single-phase potential applied between one conductor and ground with it ungrounded at other end	Voltage—1.26
F...Single-phase potential applied between one conductor and ground with it grounded at other end	Current—1.34

Summary of Conclusions

Comparison of measured and computed constants for this type of line construction show:

1. Measured and computed positive sequence units of resistance, reactance, and susceptance are substantially equal. For most practical purposes conventional calculating methods of determining these constants are satisfactory.

2. Measured and computed zero-phase sequence impedances compare favorably. Computed values from line dimensions are satisfactory for most purposes.

3. Measured and computed constants compare favorably for a one-conductor-and-ground channel or circuit of type measured during tests.

4. Greatest difference between measured and computed line constants occurs in zero-phase-sequence resistance and reactance values. This is probably due to assumptions made and difficulty of taking into account all factors in complex physical arrangement of conductor and shield wires and connections of shield wires to ground; resistance and reactance of shield wires varies with current; position of shield wires above conductors varies along line; transpositions; and indefinite value of resistance of earth. Average earth resistivity may be less than assumed 100 ohms per meter cube as shown by values of resistance for zero-phase and one-

conductor-and-ground circuits being less than computed unit values.

5. Ratios of zero-phase-sequence resistance, reactance, and impedance to positive-phase-sequence values obtained from test measurements are less than those obtained from computed values. Ratio of susceptances as determined by measurement are slightly higher than those from computed values.

6. Measured characteristic impedance conductor-to-conductor of 409 ohms is higher than theoretical, but is near 400-ohm value commonly accepted.

7. Measured characteristic impedance of zero-sequence circuit is about 783 ohms and is lower than computed.

8. Measured and computed characteristic impedance conductor-to-ground with shield wires is about 550 ohms depending on current magnitude and ground conditions. One-conductor-and-ground circuit without shield wires may have characteristic impedance much greater than 550 ohms. Thus carrier relay tuning equipment connected between one conductor and ground should have adjustment range sufficient to permit matching impedances considerably above 400- and 500-ohm values commonly used for open-wire transmission circuits.

9. Zero-phase-sequence and one-conductor-and-ground circuit measurements were made with comparatively small currents flowing in shield wires, due principally to inherent low voltage of test method. Although resistance and reactance of shield wires vary with current magnitude and may be a different value during fault conditions when higher currents flow than when measured using low currents, values obtained by measurement check conventional methods of computing line constants.

10. Exact methods should be used in calculations to determine ground and phase currents for relay settings on long transmission lines. Short-line or approximate methods can result in errors of considerable magnitude.

Appendix I. Computation Procedure

Short- and open-circuit impedances viewed from instrument end and listed in Table I were determined from ammeter, voltmeter, and wattmeter readings. Pillar and architrave values of equivalent π network described in Appendix II were computed by means discussed in Appendix III. *ABCD* constants of network were determined from these by formulas given in Appendix IV, and were checked using rule $A \times D - B \times C = 1$ as well as other relationships listed in Appendix IV. Unit or per-mile values of resistance, reactance, and susceptance were determined from these *ABCD* constants by a cut-and-try procedure discussed in Appendix IV. A second group of *ABCD* constants was calculated from these unit values and compared with original *ABCD* constants as a check on the per mile values to see that they would yield constants equal to those from which they were derived. This procedure was followed for positive-phase, zero-phase, and one-conductor-and-ground network constants.

Unit positive-phase-sequence values were obtained from manufacturer of conductor and reference 4. Zero-phase-sequence and one-conductor-and-ground-circuit unit values were computed from line dimensions as explained in Appendix V. These unit values are compared with those obtained through measurement as listed in Tables II, III, and IV. *ABCD* constants were computed from these theoretical values. These constants also are compared with measured values in same tables, together with open- and short-circuit impedances and characteristic impedances. *A* and *D* constants were assumed equal.

All calculations were made on conventional 10-inch slide rules with most of them on vector types. No attempt was made to carry calculations and decimal places further than accuracy of basic test data. Considering computation procedure and that exact long-line formulas were used in determining constants and unit values, it is believed results are accurate within plus or minus one per cent.

The 60-cycle impedance of about 0.2 ohm of carrier-current traps was considered too small to be included in the calculations. Since sag and tension add only about one half of one per cent to actual length of conductors over surveyed line length, these factors were not taken into consideration.

While there may appear to be slight repetition of comparison of values, for instance characteristic impedances are given in Tables II, III, and IV and then they are summarized in Table V, this is done to acquaint reader with relative magnitude of these impedances and their relationship.

Positive-phase-sequence *A* and *C* constants in this paper differ slightly from those given previously [1] because of use of a more direct route of calculating them. That is, knowing *B* and Z_{sc}, *D* or *A* can be determined more directly from $Z_{sc} = B/D$, than from $Z'_{eq} = B/(A-1)$. However, these *ABCD* constants do not change unit values previously determined because those values are still within accuracy of method and basic data.

Appendix II. Equivalent Network

Figure 3 represents equivalent π network of transmission line used in calculating constants and checking impedance relationships of positive-phase-sequence, zero-phase-sequence, and one-conductor-and-ground circuit. For positive phase sequence, pillars represent shunt susceptance and architrave equivalent line or transfer impedance. Pillars represent line-to-ground capacitance and architrave the through impedance for all three conductors in parallel which was

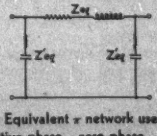


Figure 3. Equivalent π network used to represent positive-phase, zero-phase, and one-conductor-and-ground circuits

condition when basic zero-phase-sequence data were taken. For zero-phase-sequence circuit, these equivalent impedances are multiplied by three. For one-conductor-and-ground circuit, pillars represent capacitance between that conductor and ground, and architrave the through impedance.

Referring to Figure 3, Z_{oc} is open-circuit impedance looking into network with opposite end open. Z_{sc} is impedance looking into network with opposite terminals short-circuited together.

Appendix III. Relation Between Z_{eq}, Z'_{eq}, Z_{oc}, and Z_{sc}

Refer to Figure 3:

$$Z_{oc} = \frac{Z_{eq} \times Z'_{eq}}{Z_{eq} + Z'_{eq}} \tag{1}$$

$$Z_{oc} = \frac{Z'_{eq}(Z'_{eq} + Z_{eq})}{2Z'_{eq} + Z_{eq}} \tag{2}$$

From (1):

$$Z_{eq} = \frac{Z_{oc} \times Z'_{eq}}{Z'_{eq} - Z_{oc}} \tag{3}$$

Substituting this in (2) and reducing gives:

$$Z_{oc} = \frac{Z'^{2}_{eq}}{2Z'_{eq} - Z_{sc}} \tag{4}$$

Solving for Z'_{eq}:

$$Z'_{eq} = Z_{oc}\left(\sqrt{1 - \frac{Z_{sc}}{Z_{oc}}} + 1\right) \tag{5}$$

which gives Z'_{eq} in terms of measured Z_{oc} and Z_{sc} values. Substituting results from equation 5 in equation 3 gives Z_{eq}. Equations 3 and 5 were used to obtain components of equivalent π from Z_{oc} and Z_{sc} values as measured.

Appendix IV. Relationships of General Constants and Unit Values

Following formulas were used to obtain *ABCD* values from open- and short-circuit impedances, and to check results:

$$Z_{oc} = \frac{A}{C} = \frac{D}{C} \tag{6}$$

$$Z_{sc} = \frac{B}{D} = \frac{B}{A} \tag{7}$$

$$Z_{eq} = B \tag{8}$$

$$Z'_{eq} = \frac{B}{A-1} \tag{9}$$

$$A \times D - B \times C = 1 \tag{10}$$

Expressions for *ABCD* constants from references 4 and 5 are:

$$A = D = \cosh\sqrt{ZY} = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \dots\right) \tag{11}$$

$$B = \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY}$$

$$= Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \dots\right) \quad (12)$$

$$C = \sqrt{\frac{Y}{Z}} \sinh \sqrt{ZY}$$

$$= Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \dots\right) \quad (13)$$

Unit resistance, reactance, and susceptance were obtained from equations 11 and 12 and from

$$Z = L(r + jx) \quad (14)$$

$$Y = L(g + jb) \quad (15)$$

by first equating value of A obtained from Z_w and Z_{sc} to expression 11. ZY in series of (11) was found by cutting-and-trying. This was then substituted in (12), and knowing B, Z was found and then Y. Unit values were found from equations 14 and 15. Y was found to have a very small conductance component g, but this was not retained because its value was considered to be too indefinite for methods used.

Appendix V. Unit Resistance, Inductive Reactance, and Capacitive Susceptance From Line Dimensions

Positive-phase-sequence unit constants were obtained from tables and following methods given in chapter III of reference 4. Values obtained are:

r_p = 0.238 ohm per mile at 25 degrees centigrade and 60 cycles
$jx_p = j0.803$ ohm per mile
$jb_p = j5.18$ micromhos per mile

These do not include effect of earth and shield wires.

Zero-phase-sequence unit constants were obtained following methods given in chapters VII, VIII, and IX of reference 5 and chapters XI and XII of reference 6. Values obtained are:

r_0 = 0.829 ohm per mile at 25 degrees centigrade and 60 cycles
$jx_0 = j2.28$ ohms per mile
$jb_0 = j3.65$ micromhos per mile

These include effect of shield wires. Average spacings and geometric-mean-distances were used in an effort to include effect of transpositions and different sag of conductors and shield wires.

Unit constants of one-conductor-and-ground circuit were obtained following methods given in chapters VII, VIII, and IX of reference 5 and chapters XI and XII of reference 6. Values obtained are:

r_1 = 0.438 ohm per mile at 25 degrees centigrade and 60 cycles
$jx_1 = j1.3$ ohms per mile
$jb_1 = j4.6$ micromhos per mile

These values include effect of shield wires. An average geometric-mean-distance between one conductor and shield wires was used in calculations for unit inductive reactance. Likewise average spacings were used in calculations for unit capacitive susceptance.

Following is a summary of basic assumptions, geometric-mean-radii, geometric-mean-distances, and related data used in computing unit constants from line dimensions:

An earth resistivity of 100 ohms per meter cube was assumed.
Equivalent depth of earth return was taken as 2,800 feet.

Conductor diameter = 0.683 inch.
Conductor resistance = 0.238 ohm per mile at 25 degrees centigrade.
Equivalent conductor spacing = 18.25 feet.
Geometric mean radius of conductor for inductive reactance = 0.0245 foot.
Geometric mean radius of conductor group for inductive reactance = 2.02 feet.
Geometric mean radius of conductor group with 14.5 feet spacing for capacitive susceptance = 2.11 feet.

Shield wire diameter taken as 0.375 inch.
Shield wire resistance:
  For current of 1 or 2 amperes = 4 ohms per mile.
  For 40 amperes = 7.4 ohms per mile.
Shield wire geometric mean radius for inductive reactance:
  Low current of 1 or 2 amperes = 10^{-3} feet.
  For 40 amperes = 10^{-12} feet.
Geometric mean radius of shield-wire group for inductive reactance:
  Low current of 1 or 2 amperes = 0.132 foot.
  For 40 amperes = 4.18×10^{-4} feet.

Geometric mean distance of separation between conductors and shield wires = 19.55 feet.
Geometric mean radius of shield wire group for capacitive susceptance = 0.523 foot.
Geometric mean distance of separation between conductors and images for capacitive susceptance = 67 feet.
Geometric mean distance of separation between one shield wire and conductor images for capacitive susceptance = 81.5 feet.
Average geometric mean distance of separation between one conductor and shield wires for inductive reactance = 19.5 feet.

See Figure 2 for average conductor and shield-wire spacings and distance above ground.

Appendix VI. Nomenclature

$ABCD$—General constants of any four terminal network not having an internal source of voltage.
$A_2B_2C_2D_2$—Positive-phase sequence general constants.
$A_0B_0C_0D_0$—Zero-phase sequence general constants.
$A_1B_1C_1D_1$—General constants of one-conductor-and-ground circuit.
$r_p jx_p jb_p$—Positive-phase sequence per mile values of resistance and inductive reactance in ohms and capacitive susceptance in micromhos.
$r_0 jx_0 jb_0$—Zero-phase squence per mile values of resistance and inductive reactance in ohms and capacitive susceptance in micromhos.
$r_1 jx_1 jb_1$—One-conductor-and-ground per mile values of resistance and inductive reactance in ohms and capacitive susceptance in micromhos.
Z_{osp}, Z_{ssp}—Positive-phase-sequence impedance in ohms looking into line with far end open-circuited and short-circuited, respectively.
Z_{osc}, Z_{ssc}—Zero-phase sequence impedance in ohms looking into line with far end open-circuited and short-circuited to ground respectively. These are three times impedances obtained with all three conductors paralleled.
Z_{osi}, Z_{ssi}—Impedance looking into one-conductor-and-ground circuit with far end open-circuited and short-circuited to ground, respectively.
Z_{eq}—B constant or architrave of equivalent general π network in ohms.
Z'_{eq}—Impedance of shunt path in ohms at two ends or pillars of π network.
Z/θ—Impedance in ohms.
z/θ—Impedance, ohms per mile.
$Z_r Z_x Z_t$—Total line impedance or $L(r_p + jx_p)$, $L(r_0 + jx_0)$, $L(r_1 + jx_1)$ respectively.
$Y_g Y_b Y_t$—Total line admittance or $L(g_p + jb_p)$, $L(g_0 + jb_0)$, $L(g_1 + jb_1)$ respectively.
L—Line length in miles.

References

1. Staged-Fault Tests of Relaying and Stability on Kansas–Nebraska 270-Mile 154-Kv Interconnection, C. W. Minard, R. B. Gow, W. A. Wolfe, and E. A. Swanson. AIEE Transactions, volume 62, 1943, pages 358–67; discussion, pages 425–6.

2. Performance Requirements for Relays on Unusually Long Transmission Lines, F. C. Poage, C. A. Streifus, D. M. MacGregor, and E. E. George. AIEE Transactions, volume 62, 1943, June section, pages 275–83; discussion, pages 422–5.

3. Protective Relaying on Long Transmission Lines, A. R. van C. Warrington. AIEE Transactions, volume 62, 1943, June section pages 261–8; discussion, page 427.

4. Electrical Transmission and Distribution Reference Book (first edition), Westinghouse Electric and Manufacturing Company, 1942.

5. Symmetrical Components, C. F. Wagner and R. D. Evans. McGraw-Hill Book Company, Inc., New York, N. Y., 1937.

6. Circuit Analysis of A-C Power Systems, Edith Clarke. John Wiley and Sons, 1943.

7. Zero-Sequence Impedances of Overhead Three-Phase and Single-Phase Transmission Circuits, Edith Clarke and G. K. Carter. *General Electric Review*, volume 44, June 1941, pages 329–36.

8. Calculation of Unbalanced Voltage Drops in Distribution Circuits With Particular Reference to Multigrounded Neutrals, W. R. Bullard, H. L. Lowe, and H. W. Wahlquist. AIEE Transactions, volume 63, 1944, April section, pages 145–8.

9. The Electrostatic Unbalance of Transmission Lines and Its Effect on the Application of Petersen Coils, J. A. M. Lyon. AIEE Transactions, volume 58, 1939, March section, pages 107–12; discussion, page 574.

A Pneumatic Mechanism for Outdoor Oil Circuit Breakers

L. J. LINDE
ASSOCIATE AIEE

E. B. RIETZ
ASSOCIATE AIEE

OPERATING mechanisms for power circuit breakers differ from most machines in that:

1. Moderate amounts of energy must be released quickly and easily at a high power rate.

2. Energy must be available for their operation under emergency conditions, particularly when normal power sources would be interrupted.

These particular conditions are satisfied readily by a stored-energy system where energy is accumulated with moderate rates of power and held ready for instant consumption. Stored-energy systems can be selected in many forms. The rubber bands of a toy airplane are one form, the rocket projectal another. Switchgear however places a premium on reliability, not on lightness or novelty, a demand that considerably restricts the practical choices that can be made.

Of the several choices that are available, storage batteries, compressed springs, and compressed-air systems have histories of satisfactory applications as energy accumulators for power circuit breakers. The high closing speeds of modern oil circuit breakers demand a rather large amount of power during a short interval of time. The larger circuit breakers may require more than 5,000 foot-pounds in 20 cycles during closing. To close a breaker, the mechanism must transform 20 kw of power to mechanical energy. Such demands for power can be supplied most efficiently from an energy accumulator located close to the circuit breaker. Losses over any distance naturally will reduce the available power at the breaker unless the capacity of the transmission channel, such as control-power leads or air lines, is increased considerably. Storage batteries suffer that particular handicap. They are economical when located centrally, and where they can be properly maintained and protected. They are not economical nor very practical when placed adjacent to each of a scattered group of circuit breakers. With batteries located at a central point, the *IR* drop of the control leads is of concern when control power is distributed over the distances to the breakers of a high-voltage yard.

Energy, however, can be economically and practically stored at each circuit breaker as compressed air or as stressed springs. Air can be compressed by small commercial motor-driven air compressors, stored in a moderate-size tank and released by an electrically operated control valve. Energy also can be accumulated and stored by compressing springs through a motor and gear-reduction unit, released and controlled by a suitable system of levers and latches. The methods of accumulating, storing, releasing, and controlling the energy of these media determine the success of the final circuit breaker under operating conditions. The mechanism discussed in this paper uses compressed air as the stored-energy operator. The choice has been made after a careful analysis of the listed advantages:

1. Energy is accumulated through a simple and familiar fractional-horsepower motor and standard air compressor. Power demands are held to a low value.

2. The energy is stored in an air-storage tank at the circuit breaker.

3. The closing power is released and controlled through a low-energy electrically operated air valve, other mechanical reductions being unnecessary.

4. Compressed air has little inertia. It is fast, and its resilience moderates accelerating forces.

5. The speed of response and lack of inertia of compressed air permit a ready reversal of flow to trip free the contacts of a circuit breaker.

Against these choices must be considered the apparent handicaps of compressed-air systems:

1. Storage must be nearly airtight, and, theoretically, leakage must never equal the rate of accumulation by the compressor. Practically, the leakage should be held to a small percentage of this rate.

2. Moisture in the air may give difficulties at freezing temperatures.

The mechanism here described has been developed with emphasis on the elimination or control of the handicaps listed. Practical solutions to the problems of moisture formation with freezing and air leakage have been developed and tested carefully. It is believed that this compressed-air system offers the advantages of a stored-energy system not readily available in other conventional operating mechanisms. See Figure 1.

Operating Characteristics

The value of a circuit-breaker operating mechanism cannot be determined on the basis of energy storage alone, for the choice of an operating medium must include a study of operating characteristics under "closing," "tripping," "tripped free," and "immediate reclosing" performance cycles. This comparison of compressed air with other media already has been presented on the basis of energy storage. The benefits of pneumatic systems when designed to satisfy these other operating characteristics will be discussed.

Closing Characteristics

With ample energy stored at the breaker as compressed air, the breaker contacts can be closed with desirable velocity and force characteristics through an air cylinder. Air compressed above 100 pounds per square inch responds with unusual speed to control demands. Opening the air-control valve admits air to the cylinder assembly at a rate that permits full pressure build up before the contacts are in motion. Pressure is maintained at a rate determined by a controlled orifice, accelerating forces, and the opposing forces of the contacts. Figure 2A illustrates a typical pressure and travel curve as this mechanism closes a standard oil circuit breaker. Contact speeds may be controlled closely by selection of the operating pressure. A controlled flow of air limits the "runaway" and "two-stage" action on contacts characteristic of some prime movers. This two-stage action, or hesitancy when the contacts engage, is particularly undesirable when the breaker is closing against loaded lines or against fault current. Compressed air is positive and powerful in closing a circuit breaker.

Tripping Characteristics

When used with a modern tank-type oil circuit breaker, a pneumatic mechanism uses compressed air to complete only the closing operation. Tripping or opening the breaker is accomplished by simply disengaging a holding latch or prop. The release of this trip latch frees the opening and contact springs to open the contacts. The inertia of most prime movers may retard this opening speed unless the prime

Paper 44-102, recommended by the AIEE committee on protective devices for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26-30, 1944. Manuscript submitted April 29, 1944; made available for printing May 10, 1944.

L. J. LINDE is engineer, power circuit-breaker division, and E. B. RIETZ is engineer, outdoor oil-circuit-breaker section, both with General Electric Company, Philadelphia, Pa.

Figure 1. A pneumatic operating mechanism for use with frame-mounted outdoor oil circuit breakers, viewed through the right-hand doorway

mover is divorced from the contact structure by a collapsible trip linkage. Such a linkage may delay a reclosure while it resets. The compressed-air mechanism, with little inertia, does not require a collapsible trip linkage. The output crank, freed from the holding latch by the trip coil, swings to its open position, and the mechanism is prepared to reclose the circuit breaker without delay.

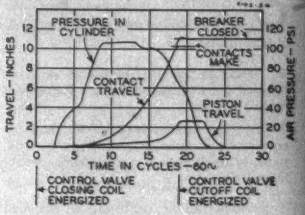
Trip-Free Characteristics

In trip-free operations it is desirable that the contacts of the breaker be reversed in their motion before a closing operation is completed. Heavy solenoids or motors, driving a closing mechanism, would be too slow in their mechanical response to a demand for reversal of motion were it not for the mechanically trip-free mechanisms employed. Such designs use collapsible linkages held rigid by a latch. Placed between the prime mover and the contact structure, this linkage can be collapsed by releasing the latch with a solenoid trip coil. The contacts of the circuit breaker, deprived of their closing force, quickly return to the open position. Unfortunately, the prime mover, being slow in mechanical response, commonly continues to drive onward, acceleration and impact forces replacing the suddenly lost contact-closing load.

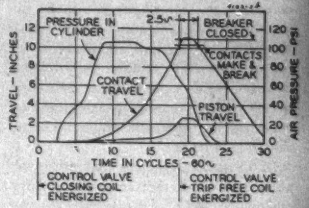
The speed of compressed air and its immediate response to control provides a practical prime mover requiring only speedy control to reverse or release its driving power within the time limits required of a trip-free operation. Fast control is provided by an electrically operated air-control valve. Power release is controlled by a dump or release valve placed in the air line between the control valve and the cylinder. This dump valve is closed or opened by the balance of pressure between the control valve and cylinder. It is closed when the control valve is open, the piston then closing the circuit breaker. If, during the closing cycle the control valve is closed, the sudden loss of pressure on the control valve side of the release or dump valve moves it to the open position, opening the cylinder port and exhausting the air in the main cylinder. With this sudden loss of pressure, and closing force, the circuit-breaker contacts return to their open position (Figure 2B). Thus a trip-free operation is affected by closing the solenoid control valve during the closing stroke of the circuit breaker. Actual operating speeds equal or may exceed those of mechanically trip-free mechanisms using collapsible linkages. Accelerating forces are not sacrificed to moving such links and levers. Excess energy is released as a blast of air from the release valve. An original design of the solenoid control valve provides the speed desirable in the electrical and pneumatic control (see Figure 4).

Immediate-Reclosing Characteristics

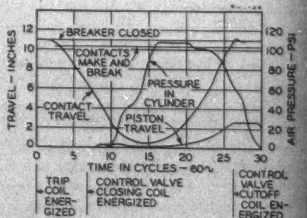
By reclosing instantaneously against a temporarily faulted line, modern oil circuit breakers have, in many applications, made a major contribution to service continuity. In many cases the worth of this contribution is dependent on the speed of reclosure. From the closed and latched position, the system may demand that the circuit be cleared and re-energized in as short a time as 20 cycles. Added to this requirement is the demand that the mechanism be prepared to trip free during the second reclosure. Mechanically trip-free mechanisms are available to satisfy these requirements. Their arrangements are generally particularly designed for such service. On the other hand the standard pneumatically trip-free mechanisms serve this purpose. The pneumatically trip-free mechanism is prepared to open, reclose, trip free, and reclose the contacts of a circuit breaker without delay in succes-



A. A closing operation with 120 pounds per square inch in the storage reservoir



B. A trip-free closing operation at 120 pounds per square inch, with the trip circuit energized through the main contacts for this no-load test. The short time in contact (2.5 cycles) demonstrates the speedy response of this pneumatic operator



C. An instantaneous-reclosing operation at 120 pounds per square inch. Attention is directed to the initial travel of the piston at low pressure. Here it meets the backward movement of the contacts, gradually stopping their motion and returning them to the closed position

Figure 2. Time-travel curves of a pneumatically operated standard outdoor oil circuit breaker

Instantaneous relations of cylinder pressure, piston travel, and breaker-contact travel are recorded. The curves are to a common scale

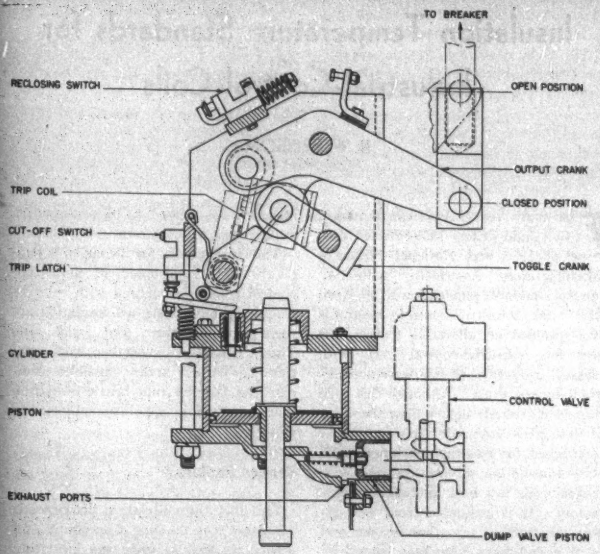


Figure 3. A diagram of a pneumatically trip-free operating mechanism latched in the closed position

The control valve has closed, pressure in the cylinder has moved the dump-valve piston to the right, uncovering the ports and exhausting the cylinder

sive operations (Figure 2C). Proper attention to control circuits makes this a most satisfactory operating mechanism for instantaneous-reclosing applications.

Description of the Mechanism

Functionally the operating mechanism may be divided into:

(*a*). The prime mover, mechanical linkage, and operating controls.

(*b*). Compressor, air-storage equipment, and controls.

The Prime Mover, Mechanical Linkage, and Controls

The arrangement of the mechanism is illustrated in Figure 1. It includes a frame, a closing linkage, a trip latch, a cylinder and piston assembly, a dump valve, and a control valve. The mechanism is supported rigidly on a pair of vertical channels forming part of the housing and bolted directly to the supporting framework of the oil circuit breaker.

The closing linkage, Figure 3, consists of the output and toggle cranks arranged to operate as rolling toggles during the closing and in the latched position. As a toggle this system adjusts the closing forces of the piston to the contacting forces of the circuit breaker. In the closed position a trip latch or prop drops under a roller on the lower toggle crank. Until this latch is forced from under this roller either by the trip solenoid or by hand, the breaker contacts are locked closed. An air-operated cylinder and piston are mounted directly to the mechanism frame. The piston plunger operates against the roller of the lower toggle crank to force the mechanism to the closed and latched position. A hydraulic jack may be used against the lower piston extension for manual operations when the breaker is being inspected or maintained. Because air pressure in the cylinder is transient, it is not necessary to seal this part of the system against normal leakage. The piston is fitted with a conventional piston ring. Mechanical clearances are not unduly close.

The operation of the air piston is controlled by an electrically operated air valve shown in Figure 4. Energizing the "operating coil" at the top of the valve lifts an armature coupled to a pilot valve. As this valve is opened, an unbalance of pressures opens the main piston valve. In the open position the armature seals against a small permanent-magnet pole piece. Near the end of the power piston's closing stroke an auxiliary switch energizes a small cutoff coil adjacent to the magnetic pole piece. The flux of the permanent magnet is shunted out by the field of this coil and releases the armature. The pilot valve and, in turn, the main control valve close. With the control valve

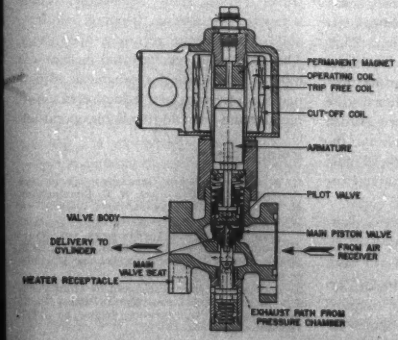


Figure 4. An electrically trip-free air-control valve

The valve is sealed open magnetically and recloses as the holding flux is shifted by energizing either the trip-free coil or the cutoff coil

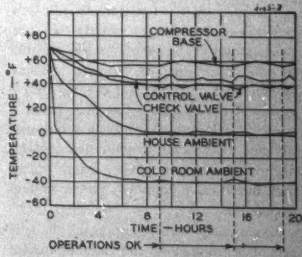


Figure 5. Records of a representative test of a pneumatic mechanism under controlled cold-room conditions

Air was accumulated in the storage reservoir while the room was at 70 degrees Fahrenheit with a relative humidity of 96 per cent. The ambient temperature of the room was then dropped to and held at 40 degrees Fahrenheit below zero. The compressor, pressure switches, control, dump, and check valves were operated at indicated intervals. Recorded temperatures are shown during this test run

closed, the dump valve slides to its open position, and the compressed air in the operating cylinder is released.

For trip-free operations a small trip-free coil similar to the cutoff coil is energized in parallel with the trip coil, the control valve is closed, and again the compressed air is released from the main cylinder. This trip-coil circuit can be energized from a conventional d-c source. The trip-coil currents are comparable to those of other mechanisms, being six amperes at 125 volts direct current.

Compressor, Air-Storage, and Control Equipment

The problems peculiar to compressed-air mechanisms for circuit breakers include reliable air storage and freedom from air stoppages due to the freezing of accumulated moisture. As an answer to these problems, every effort was made to simplify all piping and to have all such piping drain to a common sump. A minimum of joints reduces the possibility of leaks. Proper drainage reduces the difficulties with accumulated moisture.

A standard-type air compressor, driven by a fractional-horsepower motor, is mounted adjacent to the storage reservoir near the top of the mechanism housing. A coil of formed tubing serves as an after-cooler between the compressor and the storage tank. The tank, manufactured to all code requirements, has storage capacity for at least five successive breaker operations. Condensate is accumulated in a small sump at the lowest point in the house. A hand valve is used to blow off this sump.

Pressure switches control the air system. The first switch controls the compressor motor and regulates the pressure at the reservoir. A second pressure switch opens the breaker-closing-control circuit if the storage pressure is below a working minimum. A third switch can be used to operate a minimum pressure alarm. A pressure gauge, safety valve, and check valve complete the air-system accessories.

Experience with compressed-air systems has emphasized the value of careful design and design testing to prevent possible difficulties from freezing. Any troubles at freezing temperatures originate with moisture accumulations. The air lines of the operating mechanism are laid out to reduce moisture pockets to a minimum.

As a guard against freezing during subzero temperatures, small resistance heaters are installed at the control valve and on the supporting base of the compressor. A small space heater, located below the mechanism, moderates the temperature of the house. These heaters are controlled by a thermostat which energizes these heaters when the inside ambient temperature is less than 50 degrees Fahrenheit.

With these provisions, operations have proved satisfactory to 40 degrees below zero Fahrenheit, under the controlled-test conditions of a refrigerated room. During an extended series of tests in this refrigerated room the compressor accumulated air of both low and high moisture content. Continuous tests were recorded over extended periods to duplicate the more severe operating conditions. Figure 5 summarizes some of the more interesting records.

Summary

This compressed-air mechanism has been developed to answer the requirements of a simple and reliable stored-energy mechanism. By arranging this mechanism to be pneumatically trip-free, it has been possible to get the high-speed operations required of modern oil circuit breakers. The mechanism has been tested under severe operating conditions to insure trouble-free performance. Time-travel curves show satisfactory characteristics for closing, tripping, trip-free, and instantaneous reclosing operations. The absence of synchronized mechanical motions and critical mechanical adjustments contributes to a reduction in maintenance and will add to reliable operation.

References

1. A Compressed-Air Operating Mechanism for Oil Circuit Breakers, R. C. Cunningham, A. W. Hill. AIEE Transactions, volume 61, 1942, September section, pages 695–8.

2. New Multibreak Interrupter for Fast-Clearing Circuit Breakers, R. M. Spurck, H. E. Strang. AIEE Transactions, volume 57, 1938, December section, pages 705–10.

3. Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines, D. C. Prince, Philip Sporn. AIEE Transactions, volume 56, 1937, January section, pages 81–90.

Insulation Temperature Standards for Industrial-Control Coils

B. W. ERIKSON
NONMEMBER AIEE

FOR many years, American Standard C19 (Underwriters Laboratories, Inc. issue of 1938 and National Electrical Manufacturers' Association industrial-control standards publication 40-59, April 1940) for industrial-control apparatus has specified an allowable temperature rise for industrial-control coils with class-*A* insulation of 85 degrees centigrade by resistance. Although this is 25 degrees centigrade higher than the value of 60 degrees centigrade rise by resistance established for rotating machinery with class-*A* insulation, service experience with control coils has been thoroughly satisfactory. It is estimated from field experience that not more than five per cent of all coil failures have been caused by temperature, despite the frequent use of above-normal voltages. The author believes, therefore, that the present control standard has proved to be conservative with respect to temperature-rise limits.

The chief reasons for the superior temperature–life expectancy of industrial-control coils as compared with rotating machinery having class-*A* insulation are their rigid structure and small size. These conditions together with the thorough varnish sealing possible, eliminate the failures from brittle insulation that occur in large apparatus subjected to vibration.

Service Factors

This fact that insulation life depends very largely on the type of apparatus and service, as well as upon the insulating materials used, was recognized in the 1940 revision of AIEE Standard 1, as indicated by the following quotations from its preface:

". . . How long an insulation will last electrically will depend not only on the class of material used, but also on the effectiveness of the physical support for the insulation, and the severity of the physical forces tending to disrupt it. Even though portions of insulation structures of organic materials

Paper 44-140, recommended by the AIEE committee on electrical machinery for presentation at the AIEE summer technical meeting, St. Louis, Mo., June 26–30, 1944. Manuscript submitted April 13, 1944; made available for printing May 17, 1944.

B. W. Erikson is in the industrial-control engineering division, General Electric Company, Schenectady, N. Y.

have become oxidized or embrittled under the influence of high temperatures, successful operation of the windings may be obtained over further periods of years, if such insulation is not mechanically disturbed.

"In view of the important influence of mechanical stresses, thermal expansion and contraction forces impose temperature-rise limitations on larger apparatus, even though higher temperature rises have proven to be satisfactory in smaller machines.

"Insulation life is also dependent to a considerable extent upon the access of oxygen, moisture, dirt, or chemicals to the interior of the insulation structure. At a given temperature, therefore, well-impregnated windings or totally enclosed machines may have much longer insulation life than windings freely exposed to industrial atmospheres. . . .

". . . It is important that individual types of apparatus and specific-purpose applications should be free to use different temperature-rise values in accordance with their individual economic problems."

At any rate, hundreds of thousands of class-*A*-insulated industrial-control coils, designed for a rise by resistance of 85 degrees centigrade at 100 per cent voltage, have been in use in industrial applications for the past 25 years with entire success and customer satisfaction of a high order. This experience, therefore, supports the author's conviction that the temperature-rise limits should be extended:

(*a*). To take advantage of advances made in the art of coil design and manufacture.

(*b*). To utilize to the fullest possible degree opportunities offered by the many new synthetic materials which have come on the market in recent years.

Better Designs and Service

In reference to paragraph *a*, such improvements as have been made in molded compounds, varnishes, cloths, paper, and wire should be and have been reflected in better and longer-lasting coils. Designs today tend to be even smaller and more compact and for this reason do not readily deteriorate mechanically subsequent to overheating (for typical appearance of control-coil designs see Figure 1). Improvements in coil construction will result in smaller and lighter designs. These when used in contactors and relays speed up device operation, prolong life of moving parts, tend to reduce maintenance, and, in general, give greater customer satisfaction.

Also much has been learned about methods of support so that present coil designs are well and firmly held in place. This means that the drying out of the insulation at elevated temperatures will not result in mechanical failure of the insulation system. Another factor which is of considerable help is the use of class-*A* non-water-absorbent insulation materials. Old-time papers and cloths when dried out and later subjected to moisture conditions act as a wick absorbing considerable quantities of water. This action, of course, is productive of current leakage and electrolytic corrosion of the copper wires and is far more destructive to coil life than temperature aging by itself.

This temperature-aging moisture-absorption characteristic does not apply in the same degree to modern synthetic insulation materials.[1] Cellulose acetate, polystyrene, polyvinyl-chlorides, polyamides, and the glass or glass-laminated products are far better than the papers, silks, and cottons in common use when the present standards were first written. This is substantiated by field experience which has shown that temperature failures are less than five per cent of total coil failures.

New Materials

Again if we consider paragraph *b*, these new materials[2] and their applications do not fall too well within our previous concept of class-*A* materials. Nylon, for instance, is a good illustration of a material of organic origin that will withstand temperatures in excess of those permitted by AIEE class *A*. On the other hand it cannot be classified as class *B*. There are many materials of this general nature that will be available after the war.

For instance, as an illustration of the many new synthetic materials which favor a change to higher temperature standards, we have such materials as General Electric Company Permafil, Westinghouse Electric and Manufacturing Company Fosterite, Bakelite Corporation number 16,631, Columbia Corporation resin *CR* 39, and Monsanto Chemical Company number 100 type of resin, and a host of others, manufactured by such companies as Klascon, Ault and Wiborg, Marco, and others. These materials are chemically different from old-style conventional oil varnishes and beyond a doubt, far superior at elevated temperatures when properly applied.

Test Data

Actual long-time test data running into years of field experience are not available for most of these materials, operating at their top temperature limits. However, much practical field experience has been gained over the last two-year period in applications where these materials have been in demand. Such applications as common to the aviation industry are very nicely taken care of by the high power factor, high dielectric and temperature-endurance characteristics of these synthetics.

Figure 1. Typical industrial-control contactor coil

A few selected cases of test data on coils made with General Electric Company Permafil are:

A. A group of coils wound with 1,100 turns of 0.0179 wire were operated 600 hours at 185 degrees centigrade total. Slight cracking of the insulation appeared at one end of one coil, but the others remained in perfect operating condition throughout the test.

B. Another group of coils being slightly larger, approximately four inches square, and consisting of 2,000 turns 0.0126 wire have to date been operated for 850 hours at 165 degrees centigrade total temperature. To date there is no indication whatever of insulation deterioration.

C. Yet another group of coils of the paper-layer-wound variety insulated with Permafil and consisting of 6,000 turns of 0.010 wire have operated 1,000 hours at 150 degrees, centigrade without any signs of cracking, crazing, shrinkage, or other deterioration

D. A filament transformer has been operated on test 1,500 hours, with a voltage between terminals of 25 kv at a total temperature of 145 degrees centigrade. This coil is still in perfect condition.

Laboratory Tests

Much work has been done by the various laboratories interested in improving insulation materials. This, of course, applies to nearly all leading electrical manufacturers. Tests made by the author's associates include heat aging on test specimens at 150 degrees centigrade for one-year period and comparison of power factor and dielectric after this period of time. Among the ma-

terials tested, Permafil showed no deterioration during these tests. This applies as well to the electrical characteristics as to such mechanical considerations as shrinkage, cracking, discoloration, or embrittlement.

From the multitude of tests mentioned, the conclusion is evident that the heat-resistant synthetics of today are much superior to the common class-*A* materials. What shall we do with these new materials? The author believes that now is the time to appraise these newcomers to the insulation field and where available introduce them on current designs. However, to be able to do this, we must change the rules under which we operate.

New Heat-Resisting Synthetic Insulating Materials

It is recognized that all synthetics are not improvements over natural organic insulating materials. For this reason it is very difficult to classify the heat-resistant synthetics or to group them under family names; most of them do not have readily understandable names and are known only as numbers. It is proposed, therefore, that these materials be grouped under the broad title of "Heat-Resisting Synthetic Insulating Materials." The acceptance of any particular material under this definition ultimately should be dependent on proof that it meets the requirements established by a (future) test code of insulating materials, or by accelerated life tests on complete coils.

Application Problems

The existing temperature standards referred to in the introduction are based on continuous operation. This, of course, does not apply to the vast majority of control-coil uses, and for that reason recognition should be given this fact as part of the standards.

Actually, very few control coils or motors operate under continuous-service conditions. This is a point that sometimes is overlooked in considering insulating materials. Much has been written about life expectancy of class-*A* materials.[3] The literature indicates that the useful life of organic insulations such as cotton, oil, and paper, is of the order of 7 to 15 years when exposed to 105 degrees centigrade continuously, with free access of air and moisture, and that the life is halved by each 8 to 12 degrees centigrade increase in temperature. Of course, the actual life in a particular case is increased if oxygen and moisture are excluded,[4] and if exposure to maximum temperature occurs only part of the time. These latter factors account for the fact that control-coil life under present temperature-rise standards has approximated ten years, in the author's experience.

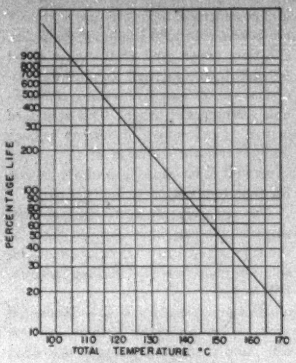


Figure 2. Effect of temperature on life of class-*A* insulated magnet coils

Taking everything into account, the author believes that an 11 degrees centigrade temperature increase for half life is the most reasonable assumption for organic insulation in agreement with reference 3 and as indicated in Figure 2. This curve is drawn with the 100 per cent life point located at 140 degrees centigrade, corresponding to 100 degrees centigrade rise over a 40 degrees centigrade ambient temperature. This curve is useful in predicting life expectancy at higher or lower temperatures of otherwise identical applications.[5]

It is expected that the new temperature-resisting synthetic materials will have an even better service life at this 140 degrees centigrade total temperature value than has been the case with the older class-*A* insulation at the present limiting temperature of 85 degrees centigrade rise plus 40 degrees centigrade ambient temperature, or 125 degrees centigrade total.

It is of extreme importance to judge such data correctly in terms of probable life under actual operating conditions. Duty cycle, ambient temperatures, time for coils to attain maximum temperature, enclosures, and all other special conditions must be considered. It is and should be the application engineers' problem to evaluate such data. This cannot be done by blind adherence to present AIEE Standards.

For instance, in the case of aircraft control coils, these are made to give satisfactory service at temperatures well above the 85 degrees centigrade rise plus 40 degrees centigrade ambient temperature. Considering expected life, this is sound application engineering and the AIEE rules should be made flexible enough to include such cases.

Hot-Spot Temperatures

With today's design practices, the hot-spot differential for industrial-control coils is much lower than in past practice and is normally below the five degrees centigrade contained in AIEE Standard 1.

The elimination of much fabric coil and layer insulation by the substitution of new extra-tough enamels and other dense materials has reduced the temperature gradient to practically zero.

Recommendations

In view of the preceding considerations, it is recommended that the following changes be made in the present AIEE Standard 1 applying to industrial-control coil designs:

1. For industrial-control coils of 600 volts rating or less, using chiefly heat-resisting insulating materials, not dependent for their insulating strength on any natural organic materials such as cotton, paper, or varnished cloth, and thoroughly impregnated with high-temperature synthetic varnishes, the permissible temperature rise by resistance should be 100 degrees centigrade.

2. For industrial-control coils of 600 volts rating or less, with insulation composed of a high percentage of inorganic materials, such as glass or mica, and wound on assemblies of heat-resisting synthetic insulating materials, the permissible temperature rise by resistance should be 120 degrees centigrade.

References

1. For descriptive data on corrosion factors: CORROSION CAUSES AND REMEDIES IN FINE-WIRE MAGNET COIL, B. W. Erikson. *Product Engineering*, March 1943.

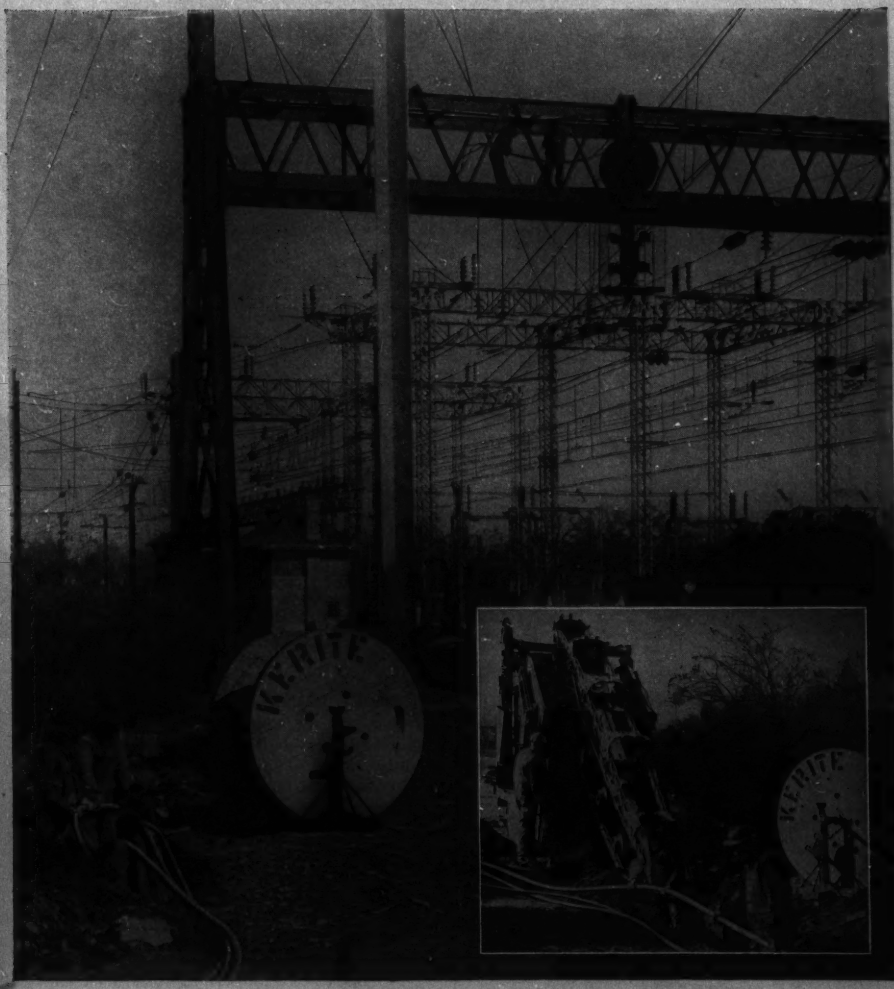
2. For an article on new materials: ELECTRICAL APPLICATION OF NEW THERMOPLASTICS, T. S. Carswell, Turner Alfrey, Jr. *Electrical World*, June 12, 1943.

3. TEMPERATURE-AGING TESTS ON CLASS-*A* INSULATED FRACTIONAL-HORSEPOWER MOTOR STATORS, J. A. Scott, B. H. Thompson. *Electrical World*, June 12, 1943.

4. CHEMICAL CHANGES AFFECTING THE STABILITY OF CELLULOSE INSULATION, F. M. Clark. Electrochemical Society *Transactions*, 83.81, April 1943.

5. APPLICATION OF APPARATUS AND CONDUCTORS UNDER VARIOUS AMBIENT-TEMPERATURE CONDITIONS, R. E. Hellmund, P. H. McAuley. AIEE TRANSACTIONS, volume 61, 1942, August section, pages 553–8. (Shows a national average of 22 degrees centigrade.)

Pioneers in Cable Engineering



SOUND CONSTRUCTION METHODS are an important contribution to the operating integrity of Kerite buried cables.

THE KERITE INSULATED WIRE & CABLE COMPANY INC
NEW YORK CHICAGO SAN FRANCISCO

The entire family of ALCOA ALUMINUM BUS BARS *is at work here—*

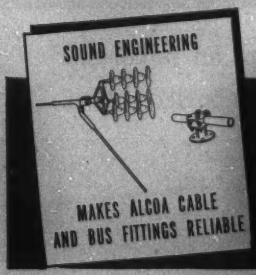
High in electrical conductivity, light in weight, corrosion-resistant, easy to handle; the designers took full advantage of these properties of aluminum in this industrial outdoor substation. Alcoa Aluminum bus bar shapes—channels, angles, flats and rounds—enabled them to meet all mechanical requirements most economically.

Vital wartime electrical loads are being carried by Alcoa Aluminum bus bars in every type of industry. Generating plants and substations, mills and factories, office buildings, battery rooms in telephone and telegraph systems; all are being supplied with power by these efficient, easy-to-maintain bus bars.

Now that the supply of aluminum exceeds the demands for military uses, Alcoa Aluminum bus bar shapes and fittings are again available. WPB Order M-1-i now permits the use of aluminum for electrical conductors. Users will find that, in installing aluminum bus bars, fewer man-hours are required. The lighter weight of aluminum makes transportation, handling and erection easier.

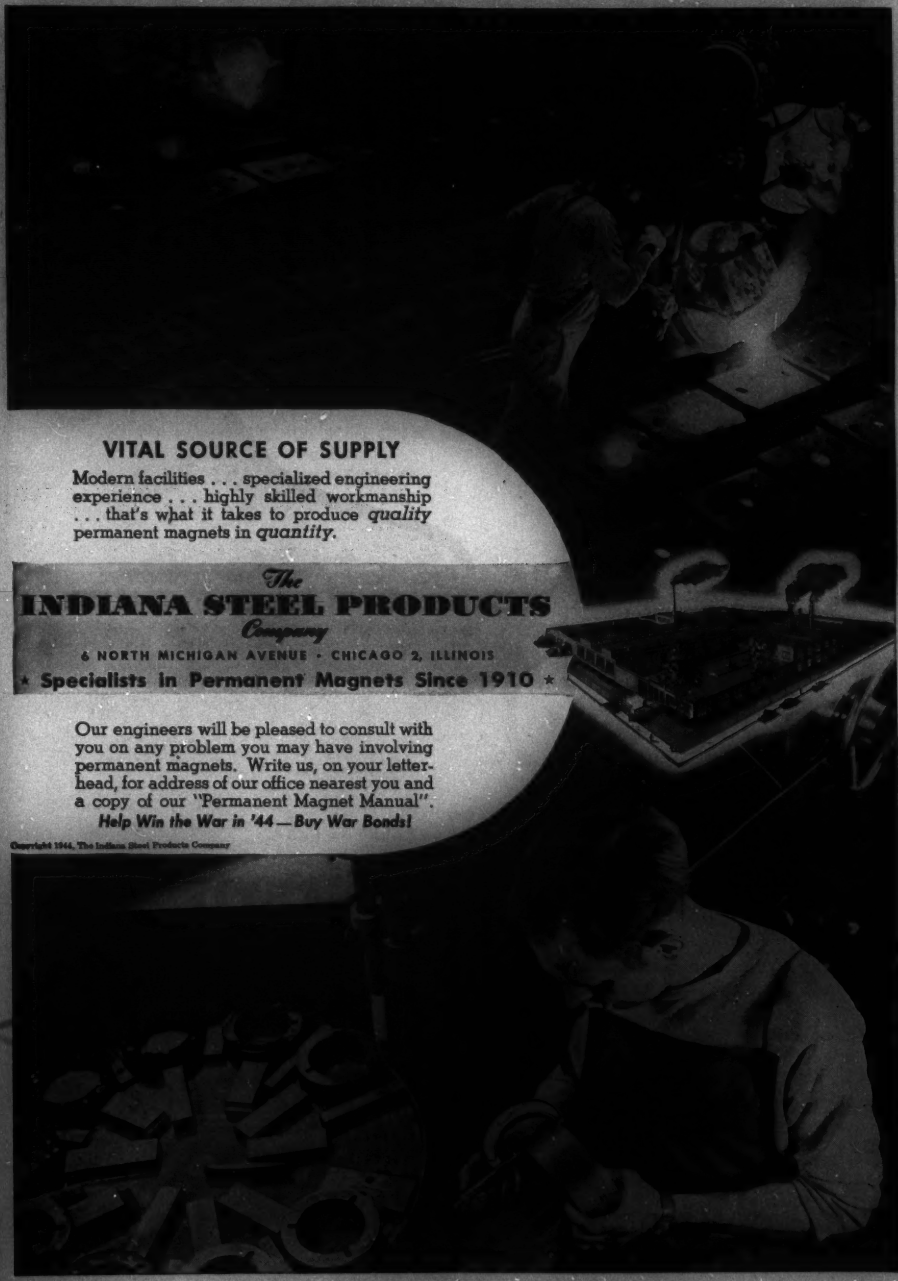
If you are considering the installation of new bus bars, or the extension of an existing system, consult Alcoa.

Our engineers are anxious to serve you. Write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.



ALCOA ALUMINUM

PERMANENT MAGNETS MAY DO IT BETTER



VITAL SOURCE OF SUPPLY

Modern facilities . . . specialized engineering experience . . . highly skilled workmanship . . . that's what it takes to produce *quality* permanent magnets in *quantity*.

The
INDIANA STEEL PRODUCTS
Company

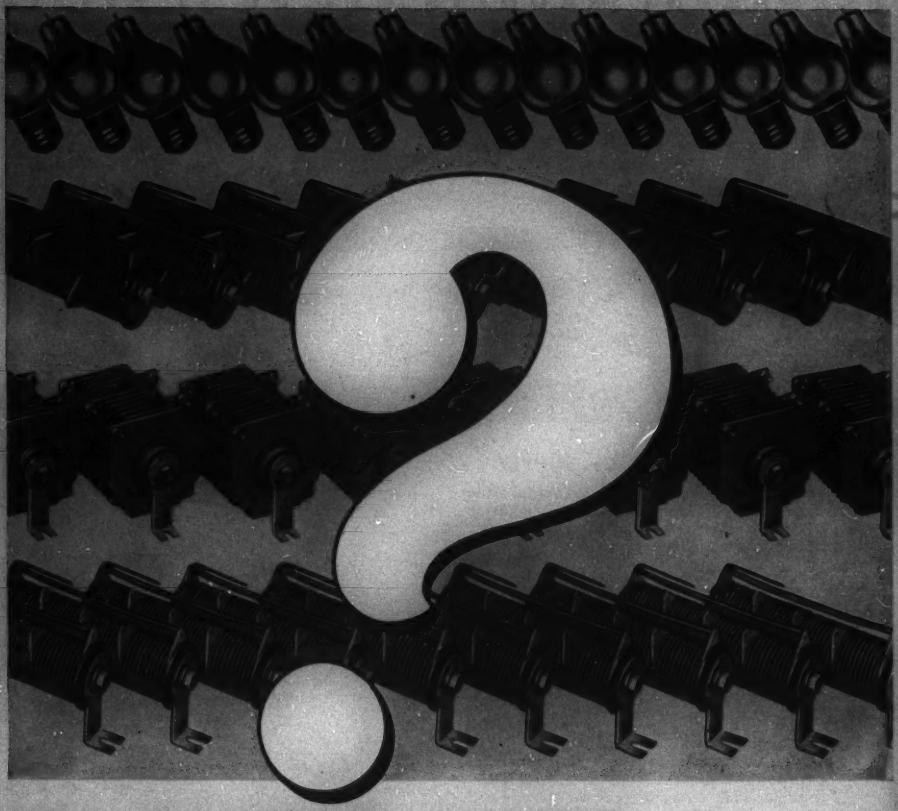
6 NORTH MICHIGAN AVENUE • CHICAGO 2, ILLINOIS

★ **Specialists in Permanent Magnets Since 1910** ★

Our engineers will be pleased to consult with you on any problem you may have involving permanent magnets. Write us, on your letterhead, for address of our office nearest you and a copy of our "Permanent Magnet Manual".

Help Win the War in '44 — Buy War Bonds!

Copyright 1944, The Indiana Steel Products Company



Are You Keeping Up-to-Date ON LOW-VOLTAGE RECTIFIERS?

1. Name the three most commonly used types of low-voltage rectifiers.

2. In what respects do they differ?

3. What is the best way to decide which type to use for a specific job?

4. Name the only designer-manufacturer of all three types.

5. What engineering-service benefit does the rectifier user get when he consults a company that offers him all three types of rectifiers?

(Turn to page 34 for the answers.)

GENERAL ELECTRIC

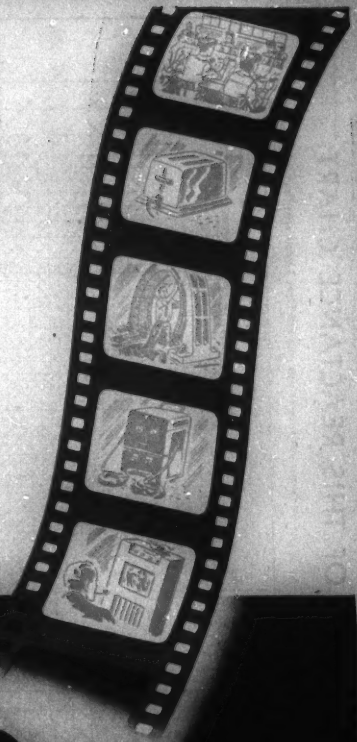
Wire AND NOTHING ELSE!

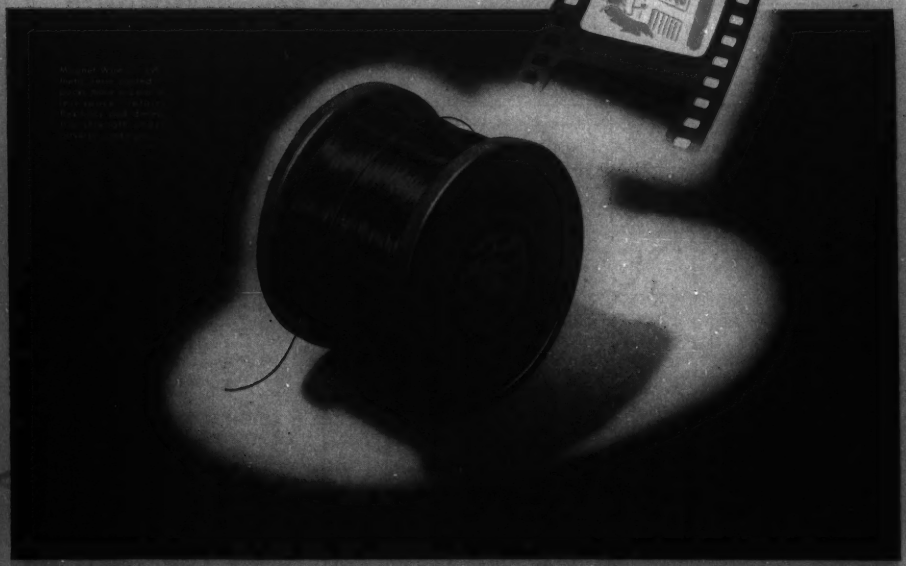
Making wire—that's the full time, all time job of Roebling *wire specialists*. Wire Specialization—that's the secret of Roebling quality.

When you see the name Roebling on a reel or coil—you know it has real significance. It stands for *integrity* in electrical wires and cables—integrity that has been the watchword of generations of Roebling wire specialists.

Give your product the *plus* in safety and dependability which Roebling electrical wires and cables assure. Available in types for all purposes—from portable cords and magnet wire to heavy power cables.

JOHN A. ROEBLING'S SONS COMPANY
TRENTON 2, NEW JERSEY
Branches and Warehouses in Principal Cities





ROEBLING

PACEMAKER IN WIRE PRODUCTS

WIRE ROPE AND STRAND • FITTINGS • AERIAL WIRE ROPE SYSTEMS • COLD ROLLED STRIP • ROUND AND SHAPED WIRE
AIRCORD, SWAGED TERMINALS AND ASSEMBLIES • SUSPENSION BRIDGES AND CABLES • ELECTRICAL WIRES AND CABLES
WIRE CLOTH AND NETTING • HIGH AND LOW CARBON ACID AND BASIC OPEN HEARTH STEELS

Please mention ELECTRICAL ENGINEERING when writing to advertisers

WRITE FOR FREE WALL SIZE COPY OF THIS REACTANCE CHART

Always use corresponding scales

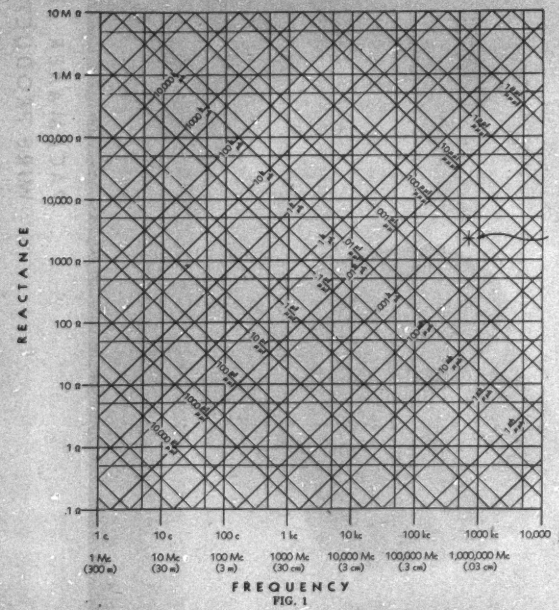


FIG. 1

Always obtain approximate value from Figure 1 before using Figure 2

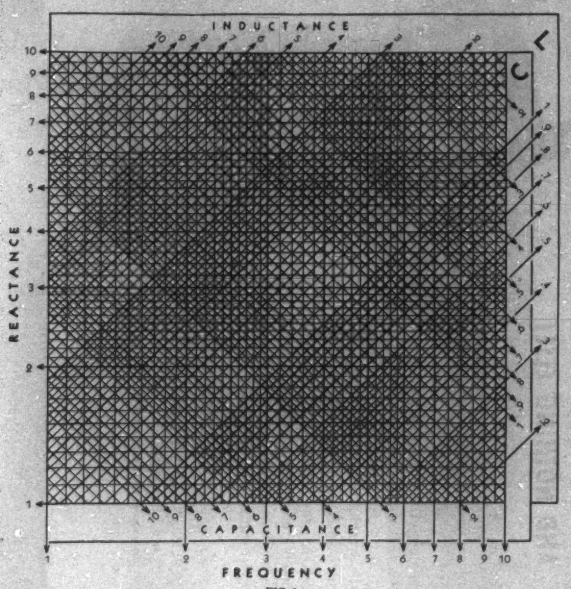


FIG. 2

The accompanying chart may be used to find:

(1) The reactance of a given inductance at a given frequency.

(2) The reactance of a given capacitance at a given frequency.

(3) The resonant frequency of a given inductance and capacitance.

In order to facilitate the determination of magnitude of the quantities involved to two or three significant figures the chart is divided into two parts. Figure 1 is the complete chart to be used for rough calculations. Figure 2, which is a single decade of Figure 1 enlarged approximately 7 times, is to be used where the significant two or three figures are to be determined.

TO FIND REACTANCE

Enter the charts vertically from the bottom (frequency) and along the lines slanting upward to the left (capacitance) or to the right (inductance). Corresponding scales (upper or lower) must be used throughout. Project horizontally to the left from the intersection and read reactance.

TO FIND RESONANT FREQUENCY

Enter the slanting lines for the given inductance and capacitance. Project downward and read resonant frequency from the bottom scale. Corresponding scales (upper or lower) must be used throughout.

Example: The sample point indicated (Figure 1) corresponds to a frequency of about 700 kc and an inductance of 500 μh, or a capacitance of 100 $\mu\mu$f, giving in either case a reactance of about 2,500 ohms. The resonant frequency of a circuit containing these values of inductance and capacitance is, of course, 700 kc, approximately.

USE OF FIGURE 2

Figure 2 is used to obtain additional precision of reading but does not place the decimal point which must be located from a preliminary entry on Figure 1. Since the chart necessarily requires two logarithmic decades for inductance and capacitance for every single decade of frequency and reactance, unless the correct decade for L and C is chosen, the calculated values of reactance and frequency will be in error by a factor of 3.16.

Example: (Continued) The reactance corresponding to 500 μh or 100 $\mu\mu$f is 2,230 ohms at 712 kc, their resonant frequency.

GENERAL RADIO COMPANY • 30 STATE STREET, CAMBRIDGE 39, MASS., U. S. A.

NEW YORK 6 CHICAGO 5 LOS ANGELES 38

Vinylite

TRADE-MARK

"Vinylite" Plastic Wire and Cable Insulation

Sets New Standards of Chemical Resistance

In many industrial applications, wire and cable insulation becomes drenched with oils and grease. Below ground, it runs through acid and alkaline soils. Frequently it is exposed to chemical fumes, the oxidizing effects of air, and the photochemical effects of sunlight. To every one of these chemical attacks, VINYLITE plastic insulation is inherently more resistant than are any of the older types of insulation.

In addition VINYLITE plastic insulation offers many other unique advantages. It is highly resistant to abrasion, stays flexible at low temperatures, and has an extraordinarily low rate of moisture absorption. It can be made in a wide range of colors. Thin wall construction, coupled with high dielectric strength, makes it possible to increase the number of circuits in existing conduits. Certain types, depending upon the plasticizer used, are non-flammable or slow-burning.

Electrical wire and cable with VINYLITE plastic insulation is today serving only essential uses. When it becomes generally available, public utility, industrial, and construction fields, marine, automotive and aircraft applications, will have these advantages of greater safety, dependability, and service life. Write Department 1 for Booklet VR. It describes the characteristics of the various VINYLITE resin compounds for wire and cable insulation and shows their specific advantages for a wide variety of applications.

Plastics Division

CARBIDE AND CARBON CHEMICALS CORPORATION

Unit of Union Carbide and Carbon Corporation

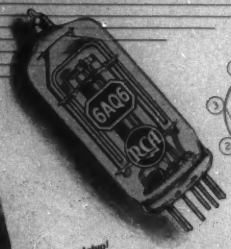
UCC

30 EAST 42ND STREET, NEW YORK 17, N.Y.

Plastics

3 NEW RCA MINIATURES

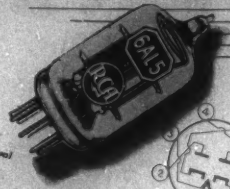
(All on the Army/Navy Preferred List)



Actual Size

RCA-6AQ6 DUPLEX-DIODE TRIODE $1.50

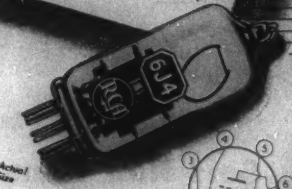
A multi-purpose miniature electrically similar to the metal 6SQ7, but with half the heater-power requirement. Primarily for use as a combined detector, amplifier, and avc tube. Diode biasing of the triode unit is not suitable. Interelectrode capacitances are low. Heater: Volts, 6.3; Amp., 0.15. Max. overall length, 2⅛ in.; seated, 1⅞ in. Triode Characteristics (class A1 Amplifier): Plate volts, 250; Grid volts, −3; Amplification factor, 70; Plate resistance, 58,000 ohms; Transconductance, 1200 micromhos; Plate current, 1.0 ma.



Actual Size

RCA-6AL5 HIGH-PERVEANCE DOUBLE DIODE $.75

A heater-cathode type of miniature twin-diode. Its low tube-drop, 10 volts at 60 ma. per plate, permits the design of high-efficiency broad-band circuits. Diodes can be used separately or in parallel. Heater: Volts, 6.3; Amp., 0.3. *Max. Ratings* (Design center values): Peak inverse plate volts, 420; Peak current per plate, 64 ma. D-C output current per plate, 9 ma.; D-C heater-cathode potential, 330 volts. Max. overall length, 1-13/16 in.; seated, 1-9/16 in.



Actual Size

RCA-6J4 HIGH-MU TRIODE MAX. FREQ.—500 Mc $8.35

A heater-cathode type of miniature triode. Excellent as a grounded-grid u-h-f amplifier (up to 500 Mc); provides high signal-to-noise ratio. Amplification factor, 55. Transconductance, 12,000 micromhos at plate current of 15 ma. Useful in conventional circuits with ungrounded grid (a-c or d-c); Amp., 0.4. Heater: Volts, 6.3 (a-c or d-c); Amp., 0.4. Max. overall length, 2⅛ in.; seated, 1⅞ in. *Max. Ratings* (Design center values): Plate volts, 150; Plate dissipation, 2.25 watts; Plate current, 20 ma. Mounts in any position.

EACH of these 3 new tubes meets an important need in the miniature field:

RCA-6J4 as a high-gain triode for frequencies up to 500 Mc

RCA-6AL5 as a high-perveance double-diode for efficient broad-band circuits

RCA-6AQ6 as a duplex-diode/triode to combine several functions in one miniature envelope

All 3 combine sturdy construction with small size and high performance.

All 3 are on the Army/Navy Preferred Type List!

All 3 were completely engineered by RCA!

Additional technical data is available on request. Ask for it by tube type number.

If you have an application involving these or other RCA tubes, get in touch with us. Our tube application engineers will be glad to help you. Radio Corporation of America, Tube & Equipment Department, Harrison, N. J.

Listen to "The Music America Loves Best" on the RCA program every Saturday, 7:30 P.M., E.W.T., Blue Network.

BUY WAR BONDS

RADIO CORPORATION OF AMERICA

RCA VICTOR division · Camden, N. J.

The Right Brain of all electronic equipment is a Tube . . . and the fountain-head of modern Tube development is RCA.

U. S. MARINES ON BOUGAINVILLE use palm trees for telephone poles as they string communication lines. Two stand guard with carbine and sub-machine gun.

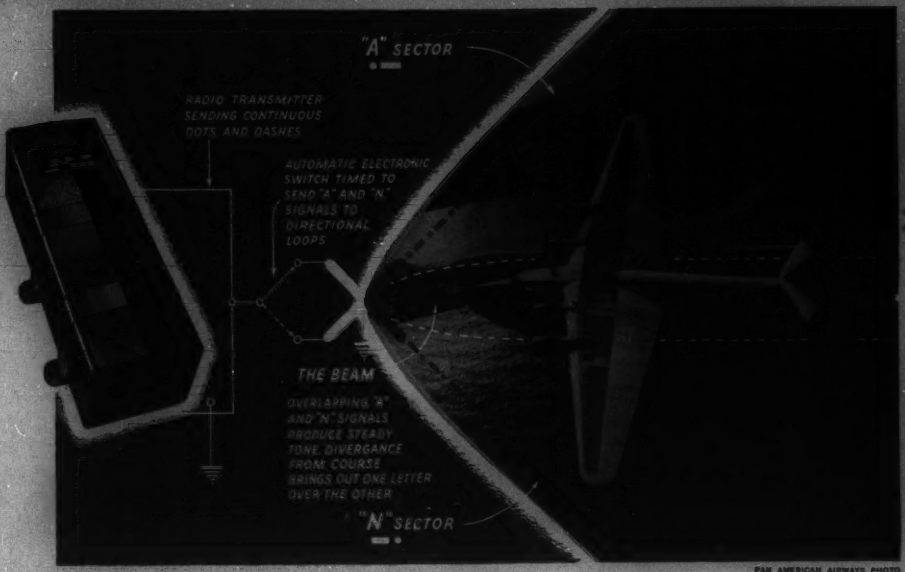
Telephone Lines on Bougainville

THIS is a war of communications. The farther our forces advance, the more wires, telephones and switchboards they need. And war stopped the making of telephones for civilian use.

We regret that many here at home cannot now get telephone service and may not be able to get it for some time.

If you are one of those who are waiting, we'd like you to know that we will do everything in our power to minimize your delay.

BELL TELEPHONE SYSTEM


"A" SECTOR
RADIO TRANSMITTER SENDING CONTINUOUS DOTS AND DASHES
AUTOMATIC ELECTRONIC SWITCH TIMED TO SEND "A" AND "N" SIGNALS TO DIRECTIONAL LOOPS
THE BEAM
OVERLAPPING "A" AND "N" SIGNALS PRODUCE STEADY TONE. DIVERGANCE FROM COURSE BRINGS OUT ONE LETTER OVER THE OTHER
"N" SECTOR

PAN AMERICAN AIRWAYS PHOTO

COMMERCIAL AIRLINES keep the beam "on the beam" with built-in CONSTANT VOLTAGE

Miles above familiar landmarks, with vision obliterated by fog, sleet or storm clouds, the steady, fused tone of the "dot dash—dash dot" in the head phones is like a soothing symphony to the ears of the airplane pilot. A fading, disrupted signal spells danger.

Thus you will find SOLA Constant Voltage Transformers operating the directional beams of most commercial air lines, and the instrument landing equipment of the C.A.A. Without this constancy of operating voltage, a steady projection of radio beams is impossible.

Radio range stations must necessarily be in constant operation and fully automatic. In most instances they are located at great distances from the airports. Anything short of instantaneous adjustment of the voltage fluctuations would be unacceptable to these instruments, too sensitive to tolerate variations exceeding ± 1%.

SOLA Constant Voltage Transformers were selected for this important assignment because of their dependable automatic operation. They have no tubes or net-works to get out of order—they require no manual supervision—they are self-protecting against short circuit—they instantly reduce voltage fluctuations as great as 30% to safe operating limits.

In designing any device dependent on precise input voltage, the design engineer's responsibility does not end with specifying the operating voltage on the label.

It is the designer's responsibility to the user to assure the availability of rated voltage at all times, by building automatic voltage control into the unit—or to instruct the user as to how constant voltage might be obtained for those devices not so equipped.

SOLA Constant Voltage Transformers are available in standard units with capacities ranging from 10VA to 15KVA. As a built-in part of electrically operated instruments or devices, special units can be custom built to exact product design specifications.

To Manufacturers:
Built-in voltage control guarantees the voltage called for on your label. Consult our engineers on details of design specifications.
Ask for Bulletin ACV-74

SOLA Constant Voltage Transformers

Transformers for: Constant Voltage • Cold Cathode Lighting • Mercury Lamps • Series Lighting • Fluorescent Lighting • X-Ray Equipment • Luminous Tube Signs Oil Burner Ignition • Radio • Power • Controls • Signal Systems • Door Bells and Chimes • etc. SOLA ELECTRIC CO., 2525 Clybourn Ave., Chicago 14, Ill.

more capacity

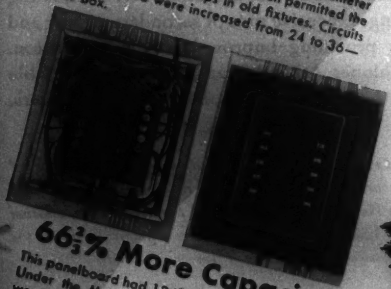
THROUGH THIS SPEEDY Square D CONVERSION PLAN

300% More Capacity!

This panel with 3 fusible circuits was converted to a modern circuit breaker installation with 12 circuits. Notice, too, that provision has been made for an additional 8 circuits whenever they are needed.

50% More Capacity!

300 watt lamps were being used. Panelboards were running hot and voltage drop was heavy. Small diameter wire and the multi-breaker Conversion Plan permitted the use of 500 and 750 watt lamps in old fixtures. Circuits in the panel illustrated were increased from 24 to 36—in the same box.



66⅔% More Capacity!

This panelboard had 12 lighting and power circuits. Under the Multi-breaker Conversion Plan, circuits were increased to 20 without removing the existing box or adding conduit.

Here are three typical examples of conversions which involved a minimum of installation time and labor and brought the following results:

- Increased panelboard capacities and added modern circuit breaker convenience and protection.
- Utilized existing boxes and conduit.
- Conserved power previously lost through over-loads.
- Eliminated the replacement of branch circuit switches and fuse clips due to excessive heating.

CALL IN A SQUARE D FIELD ENGINEER

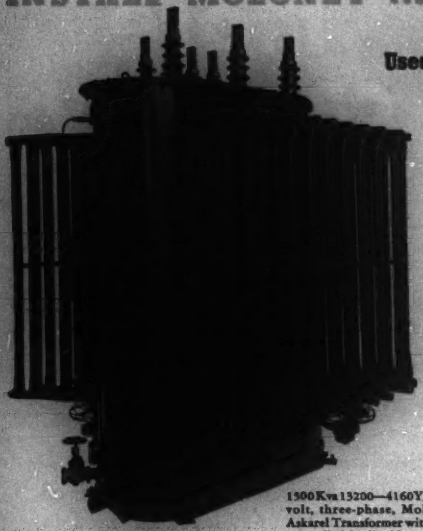
Increasing the efficiency of your electrical distribution system will help to meet today's manpower shortages and will pay big dividends in the highly competitive and narrow-margin days ahead. A Square D Field Engineer will be glad to work with you on any conversion problem.

SQUARE D COMPANY

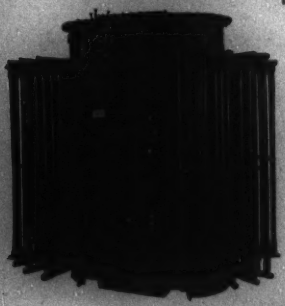
DETROIT • MILWAUKEE • LOS ANGELES

FOR *SAFETY* AND *ECONOMY*—

INSTALL MOLONEY *ASKAREL TRANSFORMERS*



1500 Kva 13200—4160Y/2400 volt, three-phase, Moloney Askarel Transformer with fans controlled by liquid temperature for increasing capacity.



1000 Kva 2400—240 x 480 volt Askarel Transformer with HV selector type disconnect switch and terminal chamber equipped with two sets of cable connections to provide a preferred and emergency feeder to the transformer.

500 Kva 4160—208Y/120 volt, three-phase, sixty cycle, Askarel Load Center Transformer with throats for connection to primary and secondary switchgear.

Used Where Non-Inflammable Transformers are Required—Either Indoors or Outdoors

MOLONEY Askarel Transformers are cooled and insulated with Askarel, a non-inflammable liquid. Because of this fact, these transformers are suited to use in applications where oil-cooled transformers would be hazardous to life and property.

Askarel Transformers are ideally adapted to indoor installation in hospital, school, hotel, theatre, office and apartment buildings—in industrial plants, mills and in central stations. They are of weatherproof construction and may be used in outdoor installations. These include in mines, on roofs of buildings, in street and sidewalk vaults for a-c network systems and many other applications where oil-cooled transformers might constitute a hazard.

These transformers effect savings in initial installation costs due to the elimination of expensive fireproof vaults. By locating the transformers at the center of the electrical load, further economies are effected by eliminating long, expensive runs of secondary copper and by providing improved voltage regulation. Moloney Askarel Transformers are available in the same ratings as oil-cooled transformers.

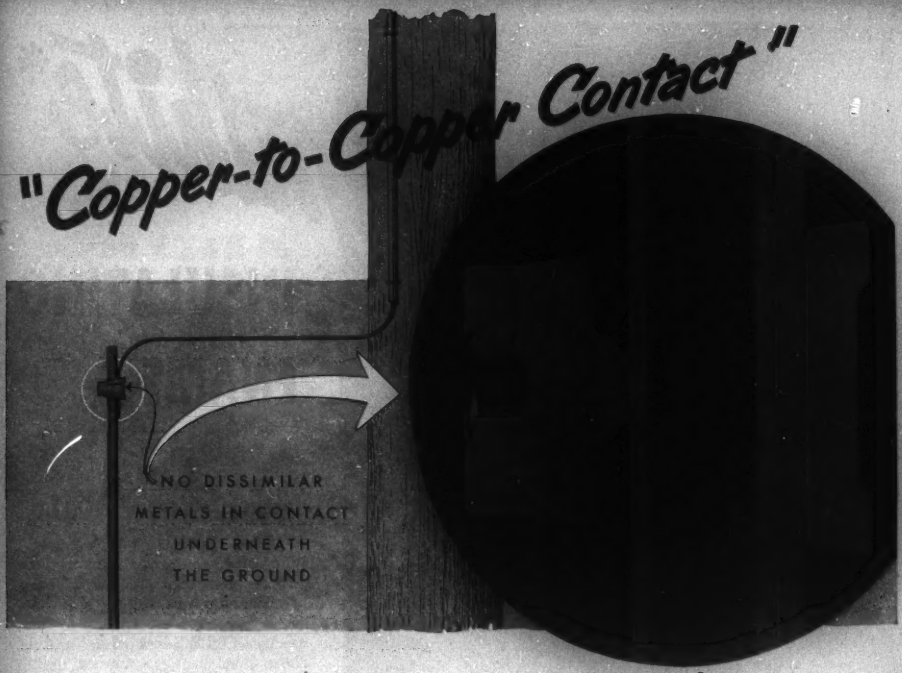
* * *

Askarel has been approved by the Underwriters' Laboratories for use as an insulating medium and the National Electrical Code permits the installation of Askarel filled transformers indoors without the necessity for providing a fire-proof vault.

MOLONEY ELECTRIC COMPANY
St. Louis, U. S. A.

MOLONEY *ASKAREL* (NON-INFLAMMABLE LIQUID-COOLED) *TRANSFORMERS*

"Copper-to-Copper Contact"



A vital point in a satisfactory ground is the connection between ground wire and ground rod. When a copper grounding wire is clamped to a Copperweld rod the connection is copper-to-copper. There are no dissimilar metals in contact under the ground to cause galvanic action or electrolytic corrosion. For ground connections that are permanently safe and dependable, specify Copperweld non-rusting ground rods.

Copperweld Steel Company • GLASSPORT, PA.

Copperweld NON-RUSTING

GROUND RODS AND CLAMPS

Synthite*

INSULATING ENAMELS

AS MOISTUREPROOF SEALERS

Where it is essential to obtain moistureproofness on metal parts, porcelain, Bakelite and also on coil windings, etc., of electrical devices, specify DOLPH'S Insulating Enamels. These insulators are the air drying type and will provide extremely high resistance to moisture, alkali and acid. The drying can be facilitated and resistive properties increased by subjecting treated units to a short bake at a low temperature.

SYNTHITE Insulators are available in clear, black, red and maroon formulations to meet various requirements. They are easy to apply by brushing, spraying and dipping and provide a glossy, tough film which has excellent adhesion to clean surfaces. Write for folder on SYNTHITE Insulating Enamels.

The DOLPH Laboratories are available to handle your problems involving moistureproofing of electrical devices. This service is rendered without obligation. Why not take advantage of this service today?

* Reg. U. S. Pat. Off.

SYNTHITE INSULATING ENAMELS PROTECT:

Molded Bakelite	Armatures	Transformers
Solenoid Coils	Bus Bars	Capacitors
Commutator Ends	Field Coils	Porcelain
Switch Bases	Motor Frames	Stators

Dolph's

JOHN C. DOLPH COMPANY

Insulating Varnish Specialists

166-8 EMMETT ST. NEWARK, N. J.

RC [illegible] BE RE[illegible]

[illegible]h TYPE M[illegible]RE WOUND RESIST[illegible]

Just as quickly [illegible]d Arms put an end to the hideous holocaust, I R C again will assume its rightful position as industry's number one source for *all* types of resistors. That greater quantities... at lower costs than ever, can be offered is established by the fact that I R C is operating on a mass production basis, the world's largest resistor plants.

ENGINEERING COUNSEL AVAILABLE

I R C's engineering staff will be glad to share with interested executives its knowledge and experience gained through years of specialization in the manufacture of resistance devices for practically every kind of application.

It is quite possible a parallel case to your own may have been already studied and solved, in which event you can save valuable time. No obligation is entailed, and, of course, your confidence will be respected.

FEATURES OF MW WIRE WOUND RESISTORS

1. *Provide light weight, low temperature rise power-type resistors for use where space and weight are vital factors.*
2. *Allow as many as six sections in a single molded resistor for flexibility of design needs.*
3. *Flat, wire wound resistor strip is insulated for mounting to chassis by high pressure molding in special asbestos-filled phenolic compound.*
4. *Permanently attached metal bracket with mounting feet permits attachment of resistor to any flat metal surface to increase heat dissipation.*
5. *Rating established at a common-sense temperature rise of 100° C.*

PREFERRED FOR PERFORMANCE · QUALITY · SERVICE

I R C

INTERNATIONAL RESISTANCE CO.

OHMITE

RHEOSTATS AND RESISTORS

Veterans of Service on Every Battle Front

In the Fight From The Beginning

Because they have helped pioneer many resistance-control applications . . . and have proved thoroughly dependable . . . Ohmite Rheostats and Resistors have been "in the fight"... *from the beginning.* Today . . . they serve in countless thousands . . . in all types of critical equipment . . . on every front. They are relied on to function day-after-day under extremes of temperature, humidity and altitude.

In resistance-control . . . Ohmite experience makes a difference. Widest range of types and sizes for every need.

BUY WAR BONDS

OHMITE MANUFACTURING COMPANY
4801 FLOURNOY STREET • CHICAGO 44, U. S. A.
Foremost Manufacturers of Rheostats, Resistors, Tap Switches

Be Right with OHMITE
RHEOSTATS • RESISTORS • TAP SWITCHES

Your Answer Book on Resistance Problems

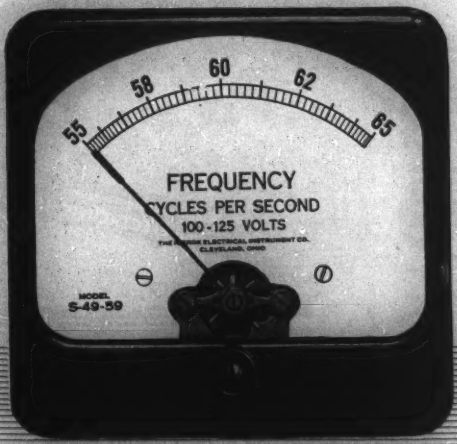
Write on company letterhead for Industrial Catalog and Engineering Manual No. 40. Gives helpful information on the selection and application of rheostats, resistors, tap switches, chokes and attenuators.

The name that is held in Highest Esteem

HICKOK

Self-Contained

Direct Indicating Type

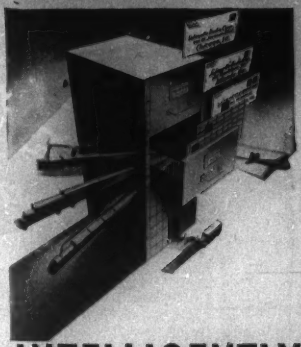


Frequency Meters

HICKOK Frequency Meters are designed with electrodynamometer movements without use of external reactor. Made to operate at an accuracy equivalent to 3/10 of 1% at normal frequency. Used by the Armed Forces of the United Nations for maximum dependability. Model S-49 illustrated, is made for normal operating voltage of 90-140 or 180-280. 4", 5" and 6" sizes. Write today for your copy of new meter catalog ready soon.

HICKOK ELECTRICAL INSTRUMENT COMPANY
10515 DUPONT AVENUE • CLEVELAND 8, OHIO

THE STANDARD OF QUALITY FOR A THIRD OF A CENTURY



INTELLIGENTLY *SPEEDILY...*

The Lafayette Radio Corp. organization, built soundly over a period of 25 years, functions in two "key" shipping centers — Atlanta and Chicago. Yes, we maintain tremendous stocks of radio and electronic components and equipment. But, equally important, there are "brains" to go with them. Our men are truly appreciative of what you are up against these days...whether you're a giant of industry, the little service man around the corner, or represent a military agency or training school.

Because we are well versed in all fields utilizing electronics, your orders are handled intelligently. At our fingertips is complete data on shipping routes, priorities, effective substitutes... all things a purchasing agent wants to know. Write, wire, telephone or teletype — get to know the superior service of Lafayette Radio Corp.

NEW — 8-Page CIRCULAR, listing merchandise available for immediate delivery, will be rushed to you on request. All items are subject to prior sale. Write or wire Dept. C-7

P.S. We specialize in equipment for laboratory and experimental use. Such equipment built to your specifications if you desire.

Lafayette Radio Corp.

901 W. Jackson Blvd. CHICAGO ILLINOIS — 265 Peachtree Street ATLANTA 3, GEORGIA

CAPACITORS *for motor-starting*

Electrolytic capacitors in required capacities and voltages, for intermittent or starting service.

•

Oil-filled capacitors for continuous or intermittent service.

•

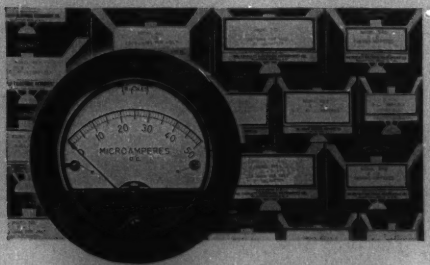
Backed by outstanding application experience, insuring satisfactory service.

•

● Always remember, Aerovox pioneered the high-capacity electrolytic capacitor for motor-starting functions. Millions of Aerovox capacitors are in daily use, especially for electric refrigerators. And Aerovox, through its many jobbers, makes certain that proper replacements are available to safeguard the good will of many equipment manufacturers. • Write for data.

AEROVOX *Capacitors*

INDIVIDUALLY TESTED



INSTRUMENT DELIVERIES!

War work has expanded Triplett production far beyond previous capacities and, with the experience of more than forty years of instrument manufacturing, has bettered the Instruments coming off the production lines.

Now—better instruments are ready for general use. Place your orders, at once, with Triplett—headquarters for instruments made to one fine standard of engineering.

D'Arsonval Moving Coil D.C. Instruments
Double Iron Repulsion A.C. Instruments
Electrodynamometer A.C.-D.C.
R.F. and Rectifier Types;
Sizes 2" through 7"

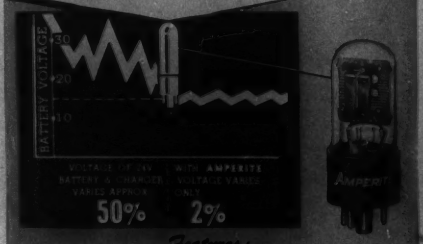
Triplett

ELECTRICAL INSTRUMENT CO.

Bluffton Ohio ★★★

ENGINEERS: Here's the BIG POINT about

AMPERITE REGULATORS



Features:

1. Amperites cut battery voltage fluctuation from approximately 50% to 2%.
2. Hermetically sealed—not affected by altitude, ambient temperature, humidity.
3. Compact . . . light . . . and inexpensive.

DELAY RELAYS: For delays from 1 to 100 seconds. Hermetically sealed. Unaffected by altitude. . . . Send for catalogue sheet.

NEW! 4-page folder will help you solve Current and Voltage Problems. Contains much valuable data in practical form — Write for your copy now.

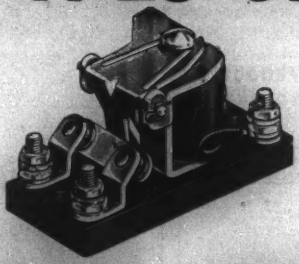
AMPERITE CO., 561 Broadway, New York (12), N. Y.
In Canada: Atlas Radio Corp. Ltd., 560 King St. W., Toronto

STRUTHERS-DUNN

INC.

5,288

TYPES OF



RELAYS

Each available in countless coil combinations

1321 ARCH STREET, PHILADELPHIA 7, PA.

DISTRICT ENGINEERING OFFICES: ATLANTA • BALTIMORE • BOSTON • BUFFALO • CHICAGO • CINCINNATI • CLEVELAND DALLAS • DENVER • DETROIT • HARTFORD • INDIANAPOLIS • LOS ANGELES • MINNEAPOLIS • MONTREAL NEW YORK • PITTSBURGH • ST. LOUIS • SAN FRANCISCO • SEATTLE • SYRACUSE • TORONTO • WASHINGTON

THIS UNIVERSAL 2-PIECE INSULATOR

For the important service in which these Acme Power Supply transformers are used, a breakdown of an insulator would be intolerable. The Universal "dry process" insulator illustrated, has helped to maintain Acme's high standards of performance. Genuine electrical porcelain is unaffected by, fumes, acids, arcing, heat or cold, and will not corrode, carbonize or oxidize.

IS TEAMED-UP WITH ACME ELECTRIC PERFORMANCE

Universal "dry process" porcelain parts are engineered to meet exacting electrical and mechanical specifications.

THE UNIVERSAL CLAY PRODUCTS CO.
1540 EAST FIRST ST. • • • SANDUSKY, OHIO

NOW more than ever

protect men and equipment!

use the

Statiscope

FOR A.C.

and KNOW that circuits are alive or dead

•

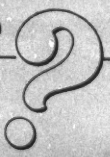
Write for Descriptive Circular

•

MINERALLAC ELECTRIC COMPANY

25 N. Peoria St. CHICAGO, ILL.

50 Church St. NEW YORK CITY

ANSWERS TO  QUESTIONS PAGE 18

Are You Keeping Up-to-date ON LOW-VOLTAGE RECTIFIERS?

1. The three most commonly used types of low-voltage rectifiers are Selenium, Copper-Oxide and Tungar.

2. They differ in characteristics, basic materials and construction.

3. The specific results to be obtained and the conditions under which the rectifier is to operate will determine which type will do the most economical, most efficient and most satisfactory job. In some applications all serve equally well, but in most instances consideration must be given to space requirements, weight, cost differences, and life expectancy.

4. The only designer-manufacturer of all three types is General Electric Co. (Tungar and Metallic Rectifier Division, Bridgeport, Conn.)

5. When the rectifier user consults General Electric, the only designer-manufacturer of all three standard types of low-voltage rectifiers, he can be assured of engineering advice on which type will meet his needs most economically and efficiently.

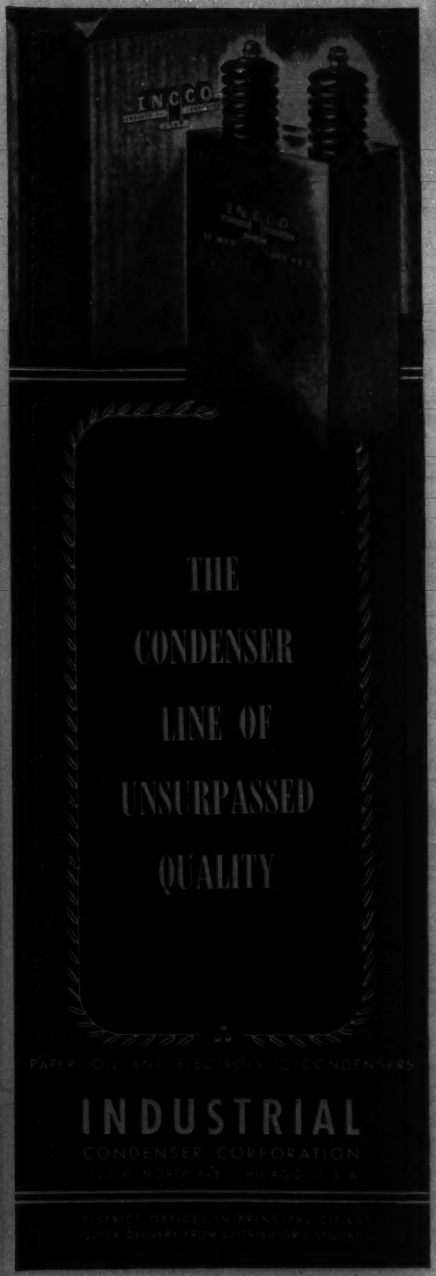
For complete details write: Section A7410-32, Tungar and Metallic Rectifier Division, General Electric Company, Bridgeport, Conn.

GENERAL ELECTRIC

Specialists for over a generation in

OIL IMMERSED MOTOR CONTROL

ROWAN CONTROL
THE ROWAN CONTROLLER CO., BALTIMORE, MD.



A STRONGER FACTOR
in TODAY'S NEW
COMPLETE CIRCUIT PROTECTION

EXTRACTOR POSTS

WITH WELDED ANTI-VIBRATION SIDE TERMINALS

NOW UNDERWRITERS' APPROVED

Resistance to extremes of shock, vibration and temperatures is provided by the new Littelfuse Extractor Posts with electrically welded side terminals. By Littelfuse process, terminals are made integral with inside metal shell. Maximum conductivity is insured. Other Littelfuse improvements for dependability, durability, and convenience make these extractor posts outstanding examples of Littelfuse *complete circuit protection.*

EXTRACTOR POST No. 341001 for 3 A G Fuses

Tool-operated. Welded side terminals. Knob and body black bakelite. Positive fuse grip. Full visual shock-proof inspection. Spring-activated cup. Specially designed grip prevents fuse from dropping out.

Also furnished finger-operated (342001).

Send for B/P and ENGINEERING DATA
Ask for Samples

Safeguard new equipment, or irreplaceable *present* equipment. Fuses, Fuse Clips, Fuse Panels, Circuit Breakers, Thermocouples, Fine Wire Products, Indicators, etc.

LITTELFUSE INCORPORATED

4757 Ravenswood Avenue, Chicago 40, Illinois

200 Ong Street, El Monte, California

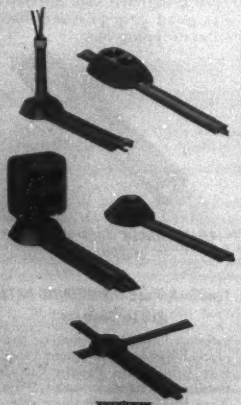
Now you can walk on wires

FITTINGS FOR EVERY REQUIREMENT

QUICK, hurry-up, safe method of getting wires across floors for electric or telephone service. Walk on "Florduct" — run hand trucks over "Florduct" — mop over "Florduct."

It is applied directly to the floor surface. Wires are laid in and capping snapped on. Eliminates hazards of open wiring.

"Florduct" is made in two sizes, designed just large enough for the wires with no extra space. Painted a neutral gray finish with complete line of fittings to match. Listed and approved by Underwriters Laboratories, Inc.



National Electric
PRODUCTS CORPORATION
Pittsburgh, Pa.

Professional Engineering Directory

BLACK & VEATCH
Consulting Engineers
Water, Steam and Electric Power Investigations, Design, Supervision of Construction, Valuation and Tests
4706 Broadway KANSAS CITY, MO.

SANDERSON & PORTER
ENGINEERS—CONSTRUCTORS
FINANCING—REORGANIZATION—
DESIGN—CONSTRUCTION
of
INDUSTRIALS and PUBLIC UTILITIES
Chicago New York San Francisco

REG. 1911 MEM. A.I.E.E.
CHRISTIAN E. BROWN
Mechanical and Electrical Engineer
DESIGNS—SPECIFICATIONS—REPORTS
Tel. 6604 MANCHESTER, CONN.

SARGENT & LUNDY
ENGINEERS
140 South Dearborn Street
CHICAGO, ILLINOIS

Member A.I.E.E.
JULIEN H. DAVIS
Consulting Engineer
Industrial
Utility—Electrical—Mechanical
740 So. Broadway Los Angeles, Calif.

THE J. G. WHITE Engineering Corporation
Design—Construction—Reports—Appraisals
80 BROAD STREET NEW YORK

FRANK F. FOWLE & CO.
Electrical and Mechanical Engineers
35 East Wacker Drive CHICAGO

WESTCOTT & MAPES INC.
Architects & Engineers
Power Plants Public Utilities
Industrial Plants
New Haven, Conn.

JACKSON & MORELAND
Engineers
Public Utilities—Industrials
Railroad Electrification
Designs and Supervision—Valuations
Economic and Operating Reports
BOSTON NEW YORK

J. W. WOPAT
Consulting Engineer
TELEPHONE ENGINEERING
Construction Supervision
Appraisals—Financial
Rate Investigations
1510 Lincoln Bank Tower, Ft. Wayne, Ind.

Z. H. POLACHEK
Reg. Patent Attorney
Professional Engineer
PATENTS OBTAINED & SEARCHED
for any invention in U. S. Pat. Off.
1234 Broadway Phone
(At 31 St.) NEW YORK Longacre 5-3088

J. G. WRAY & CO.
Engineers
Utilities and Industrial Properties
Appraisals Construction Rate Surveys
Plans Organizations Estimates
Financial Investigations Management
105 West Adams St., Chicago

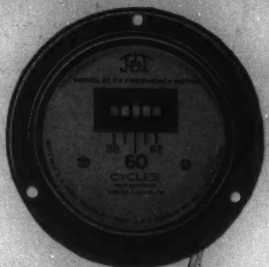
ELECTRICAL ENGINEER for Chief Engineer's Staff to analyze projects and assist in planning. Must have EE degree and several years experience in Radio, Radar and Telephone development design and manufacture. Must have an appreciation of business and accounting problems and the ability to meet and get along with people in all divisions of the Company. W.M.C. rules will be observed. Write qualifications to: Manager of Research and Engineering, Stromberg Carlson Co., Rochester 3, N. Y.

How to Read a VIBRATING REED FREQUENCY METER

in

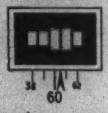
1

Easy Lesson!

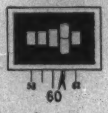


ON THE NOSE! Model 21-FX, full-cycle increment, shown indicating a frequency of 60 cycles. The 60 cycle reed is vibrating to full amplitude with the adjacent 59 and 61 cycle reeds practically at a stand still.

for example:

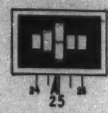


60.5 cycles. The 60 and 61 cycle reeds are vibrating equally, but to less than full amplitude. Side reeds are quiet.



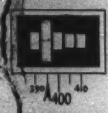
60.75 cycles. The 60 cycle reed is vibrating a little, and the 61 cycle reed is vibrating to almost full amplitude. Other reeds are quiet.

60.75 cycles. Note this is a half-cycle instrument. The 60.5 and the 61 cycle reeds are vibrating equally.



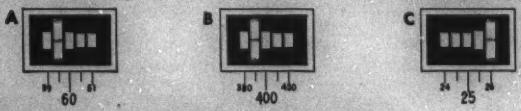
24.85. Watch the scale! Each division is one half cycle. Frequency lies between 24.5 cycles and 25 cycles and closer to 25 than 24.5.

118.0. This one is easy. Each division represents a full cycle. The 118 cycle reed has no competition in this example.



395. This is a cinch, too. How many cycles per division? Five—right. The 395 cycle reed has everything its own way, here.

Now, how good are you? Watch your Scales!



SIMPLY READ THE REED

That's Your Frequency!

Bulletin VF-43 with supplements gives detailed descriptions of the complete line of J-B-T Frequency Meters. Your copy is waiting for you.

J-B-T

Answers, but NO PEEKING

A — 59.5
B — 390.0
C — 24.6

(Manufactured under Triplett Patents and/or Patents Pending)

J-B-T INSTRUMENTS, INC.

459 CHAPEL STREET • NEW HAVEN 8, CONNECTICUT

J-BT-2

MATTHEWS CONNECTORS

For All Kinds of Wire Connections Without Solder

NUTYPE SERVICE CONNECTORS

For copper to copper—in 12 sizes.

With or without Nut Retainers.

Also available in some sizes for aluminum to aluminum and copper to aluminum connections.

SERVICE ENTRANCE CONNECTORS

A sturdy and economical means for connecting house service or other end to end copper connections (not under tension).

UNIVISE TELEPHONE

and small copper wire connector.

Vice type—strong and easily connected or disconnected.

PARALLEL CLAMPS

For connecting small tap off wires to larger main conductors at a saving.

Write for Bulletins and Samples

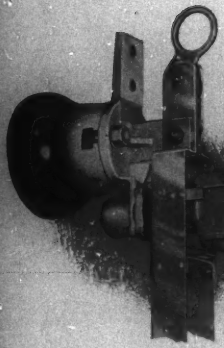
W. N. MATTHEWS CORPORATION

St. Louis, U. S. A.

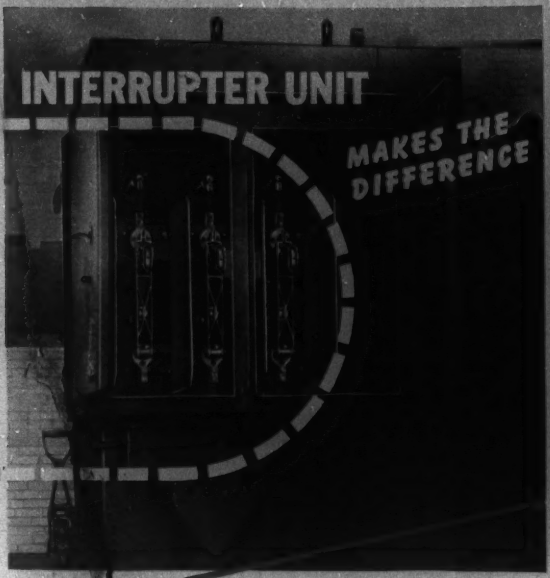
THIS MODERN LOAD-SWITCHING

Saves Space, Installation, Operating and Maintenance Costs

THE S&C INTERRUPTER UNIT MAKES THE DIFFERENCE



Breaks Load Without Arcing at Main Switch Contacts



These S & C Load Interrupter Disconnects were applied for interrupting the magnetizing current of a 2000 KVA, 13.8 KV, 3-phase transformer, and for emergency switching under full-load conditions. They were chosen on performance records of these switches as proved in hundreds of representative utility and industrial installations—chosen because of definite savings and overall reliability.

Get the facts about these and other savings on your new installations where safe, dependable load switching is required. Write for Bulletin 202-A.

* * *

S & C Load Interrupter Switches and Power Fuse combinations also have found wide application in: sectionalizing feeder circuits under load, emergency load-switching of substation transformers, isolating feeder taps and capacitor banks, and for short-circuit protection on primaries of industrial customer substations.

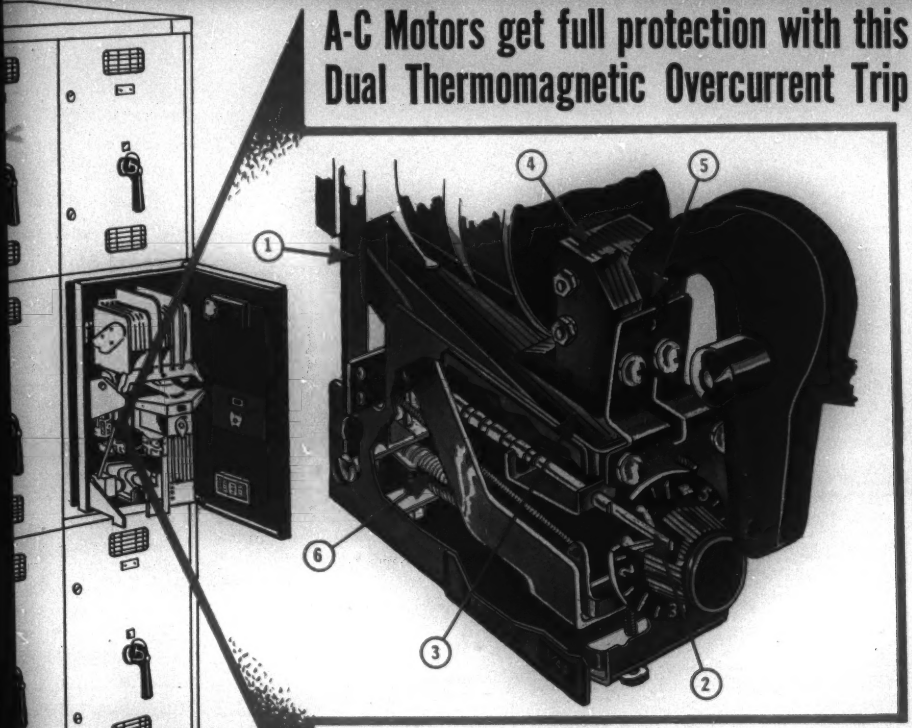
SCHWEITZER & CONRAD, INC.
4435 Ravenswood Ave., Chicago 40

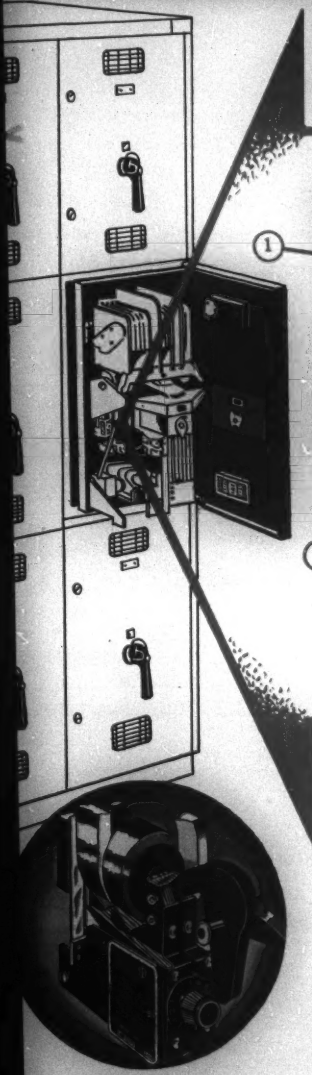
Supplied in Canada through Powerlite Devices, Ltd., Toronto, Ontario

LOAD INTERRUPTER DISCONNECT

WITH S&C INTERRUPTER UNIT

A-C Motors get full protection with this Dual Thermomagnetic Overcurrent Trip





unted on the side of each Thermomag-ic Overcurrent Trip is a plate showing ical time-load curves corresponding to ntified dial settings. The dial is notched permit intermediate settings, numbering een in all. A spring lock prevents acci-ntal turning of the knob.

(1) **BIMETAL ELEMENT**, heated inductively, causes circuit breaker to open on normal overloads only after a selected time delay. Full voltage starting is permitted with heavy inertia loads yet protection is given against light, continuous overloads such as single phasing. Heating of the element is so arranged as to avoid burnout or permanent distortion. No current flows through the bimetal.

(2) This **SHAFT** is moved forward by the heated bimetal element in starting the action of tripping the circuit breaker. The tripping effect of the forward motion is adjustable at the knob into which the shaft fits. This is like changing the bimetal heating characteristics in relation to the characteristics of the protected motor or in relation to ambient temperature.

(3) This **ARMATURE** moves, in tripping action, either in response to a preselected temperature in the bimetal or to the existence of an overload in the motor circuit equal to twelve times the rated current of the circuit breaker. This gives instantaneous opening on short circuits yet provides time delay for starting peaks and light overloads.

(4) An **ELECTROMAGNET**, energized by a surrounding series coil, has three functions: to attract the armature for direct tripping of the circuit breaker in response to extremely heavy overloads and short circuits; to serve in inductively heating the bimetal element on light overloads and by saturation to control the effect of overcurrents on the heated parts in order to prevent burnout or damage to the bimetal element.

(5) A **TRIPPING PIN** is driven against the latch of the circuit breaker when the armature is attracted to the magnet. Circuit conditions which affect the magnet are directly translated into circuit-opening action when opening is necessary.

(6) This **SPRING**, which carries no current, is preloaded to supply the correct restraint on the armature so that overcurrent of less than 12 times the rated current of the circuit breaker will cause opening only after an exactly appropriate time delay.

In combining the best characteristics of thermal overload devices and magnetic tripping, the I-T-E Thermomagnetic Trip provides protection for individual A-C motors against the effects of both light and heavy overloads. The breaker is tripped before dangerous motor temperatures are reached, but the breaker is not opened needlessly. The time-current characteristics of the device can be adjusted in exact keeping with the heating characteristics of the motor. Motors so protected can be used at full rating. For complete information, call your nearest I-T-E representative or write to I-T-E Circuit Breaker Company, 19th and Hamilton Streets, Philadelphia 30, Pa.

Representatives in Principal Cities

I-T-E

AIR SWITCHGEAR

New

INTERNAL-PIVOT PANEL INSTRUMENTS

2½- inch—1 inch deep

For radio and other communications service: Type DW-51 d-c voltmeters, ammeters, milliammeters, and microammeters; Type DW-32 radio-frequency ammeters (a-c thermocouple-type). Cases are brass or molded Textolite.

A New Design That Puts *More* Instrument into *Less* Space

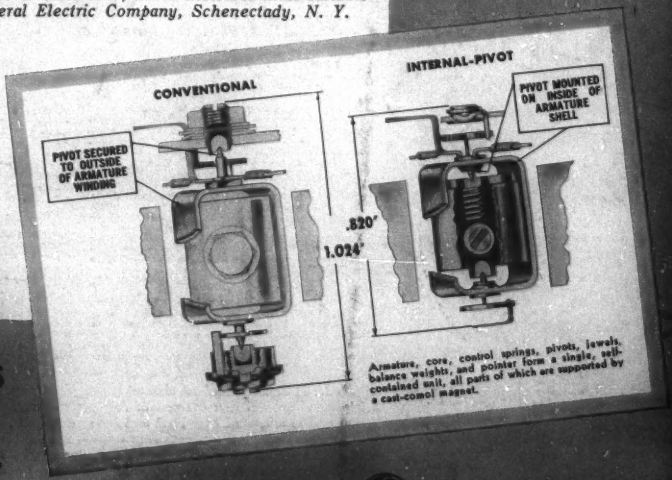
These new, internal-pivot instruments were developed to fill a vital need—particularly in the radio and aircraft fields—the need for compactness. They are *thin*—in most ratings, less than 1 inch deep.

More important is the way their thinness was achieved. In the sketch below, see how the pivots are solidly anchored to the *inside* of the armature shell so they cannot work loose. The moving parts are permanently aligned with stationary parts by bolting the core assembly to a one-piece cast-comol magnet.

Other features are: large-radius pivots, high torque and good damping, lightweight moving element, and ample clearances. Added up, they give you an instrument well able to withstand vibration and hold its rated accuracy, one that is fast on response and easy to read accurately—a design that packs all-round fine performance in a small space.

For ratings, price, and dimensions, ask our nearest office for Bulletin GEA-4064, which covers instruments for radio and other communications equipment; or Bulletin GEA-4117, which describes those suitable for naval aircraft. *General Electric Company, Schenectady, N. Y.*

Type DW-53 d-c voltmeters, ammeters, and volt-ammeters that are specially designed to measure voltage and current in battery and battery-charging circuits on naval aircraft. They meet applicable Navy specifications.


CONVENTIONAL
INTERNAL-PIVOT
PIVOT SECURED TO OUTSIDE OF ARMATURE WINDING
PIVOT MOUNTED ON INSIDE OF ARMATURE SHELL
.820"
1.024"
Armature, core, control springs, pivots, jewels, balance weights, and pointer form a single, self-contained unit, all parts of which are supported by a cast-comol magnet.

Invest in your future
BUY WAR BONDS

HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC